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ASSESSMENT OF ECOLOGICAL EFFECTS OF EXTENSIVE OR REPEATED USE OF HERBICIDES

FINAL REPORT
15 August - 1 December 1967

Contract No. DAHC15-68-C-0119

MRI Project No. 3103-B

Sponsored by

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ASSESSMENT OF ECOLOGICAL EFFECTS OF EXTENSIVE OR REPEATED USE OF HERBICIDES

by

W. B. House
L. H. Goodson
H. M. Gadberry
K. W. Dockter

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PREFACE

This report was prepared by the Midwest Research Institute under Contract No. DAHC-15-68-C-0119 for the Advanced Research Projects Agency of the Department of Defense. The authors include William B. House, Director of Biological Sciences; Louis H. Goodson, Senior Advisor for Biology; Howard M. Gadberry, Senior Advisor for Technology; Kenneth W. Dockter, Senior Biochemist; David A. Ringle, Principal Physiologist; John O. MacFarlane, Head of the Life Sciences Section and O. B. Gerrish, Head of Food Science Section. The following consultants assisted in the writing, correction of preliminary drafts, and provided ecological perspective in the areas of their special knowledge: Dr. Boysie E. Day, Professor of Plant Physiology, and Chairman of the Department of Horticulture, University of California, Riverside, California; Dr. Norlan C. Henderson, Associate Professor of Botany and Ecology, University of Missouri at Kansas City, Missouri; and Dr. James H. Jenkins, Professor of Wildlife Management, School of Forestry, University of Georgia, Athens, Georgia.

We also wish to thank those people and their organizations whose names are shown below for their assistance in providing information for use in this report. Many of the following people contributed reprints, manuscripts, and unpublished information which were invaluable to us in assembling these data.

Although we have utilized information and the suggestions from many sources the statements, opinions and recommendations offered by the authors of this report are entirely their own and do not necessarily reflect the opinion of the Department of Defense or other government agencies.

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30 November 1967

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ABSTRACT

An information survey including published literature and personal interviews with individuals knowledgeable in the fields of herbicide usage, animal ecology and plant ecology has been conducted for the purpose of assessing the ecological consequences of extensive or repeated use of herbicides for vegetation control. The general subjects discussed in this review include (1) herbicide production, usage and trends; (2) herbicide application to crop and noncroplands, especially forests, ranges, rights-of-way, waterways, ponds, lakes and reservoirs; (3) military usage of herbicides in Vietnam; (4) acute, subacute and chronic toxicities of 21 herbicides used primarily for noncropland application; (5) persistence and elimination of herbicides from the soil (6) known ecological effects of vegetation removal by chemical methods (e.g., herbicides) and physical methods (e.g., bulldozing, fire, flooding, etc.), including both the effects on the biotic and abiotic components. Specifically, consideration is given to the effects of herbicides on wildlife, wildlife habitat, endangered species, food chains, biotic potential, plant succession, animal succession, revegetation, climate, soil erosion, laterization and related topics; (7) some conclusion regarding the ecological changes are presented; and (8) some recommendations for further ecological investigations are given.

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I. INTRODUCTION

Men have altered the environment of the earth according to their will, and have done so either for an advantage or for a disadvantage which they did not foresee. If further alterations are to be for our long-term good, we need greater sensitivity and awareness of the possible consequences of our immediate and future action. A broader base of knowledge must be developed in order to exercise our best judgment. The management of resources and environment everywhere affects man's ability to provide for himself. The management of environment should be of international concern. Urban dwellers throughout the world are conscious of the lack of purity in the air they breathe. The disposal of wastes concerns the city, the state, and the national welfare. Within recent years, men have been exposed to radioactive fallouts, and have suffered from poor conservation practices. We know that pollution can be reduced and controlled. Radioactive fallout can be minimized by international agreements. Conservation policies of some natural resources have been and are being developed. Mismanagement of certain vital sectors of the environment leads rapidly down the road of no return.

> When soil is eroded, it's gone forever.
> When a biological species has become extinct, man can never make another.
> If the biotic factors of the ecology are so disturbed that they in turn alter the abiotic factors, the consequences are long-lasting.

To provide the greatest good for the greatest number at optimum cost, and to do so by a decision, the results of which will last more than one generation, we must critically study the costs and relate them to the benefits. Since all the hidden penalties and the benefits will be inherited by our children, short-term expediency must be weighed against long-term consequences. It is obvious that all the needed decisions will not be acceptable to everyone. Judgments and values (based on esthetic considerations, cost benefits, etc.) involve a review of widely divergent opinions. Extreme views must be evaluated without bias; they serve to sharpen our awareness. Because what needs to be done--and how it will be done--varies with each problem, the future of environmental management will inevitably require compromises. For example, as citizens, as people of responsibility, we feel the need to preserve a sufficient number of buffalo so that our children may have the opportunity to recapture the vision of their forefathers and the days of westward expansion. On the other hand, it does not seem desirable to allow buffalo to increase to their former numbers; they would again occupy the lands now grazed by the cattle and sheep--the sources of our beef and mutton.

The scientific field which provides the elements of the solution to the problem of environmental management is ecology which, since 1900, has been recognized as a distinct field of biology. Only in recent years has the word become a part of the general vocabulary quoted in news media. Briefly defined, ecology is a study of the interrelationships of organisms in and to their complete environment. Since the definition of ecology is necessarily broad, the concepts are broad, but not a bit less important because of their broadness. The science of ecology is achieving recognition as an important factor in human affairs.

Ecology in its development toward greater maturity needs to acquire a better quantitative technology such as the use of the systems approach. Systems analysis can more nearly cope with the trmendous number of variables and their interrelationships as represented in an ecosystem.

The use of fire, the axe, and the plow as tools to create greater agricultural productivity and to clear the land for dwellings, factories and roadways, has caused major ecological disturbances. Within the last 20 years the use of chemicals for the control of environment has expanded dramatically. Incidents involving poor management of herbicide use has caused concern among scientists which has come to the attention of the public. Sometimes the public is not equally reminded that the suppliers of food, fibers, and timber are confronted with production problems, the solution of which depends on the success of the continuing fight against pollution, disease, and pests.

This review assesses the ecological consequences of the extensive or repeated use of herbicides. The basic intent of our investigation has been to examine the status of the knowledge about the ecological consequences to be expected from the extensive use of these vegetation-control chemicals. We are concerned with herbicides used in such a manner that they disturb ecosystems to the point that severe effects could ensue: e.g., erosion, the extinction of species, or the loss of land fertility. In our past history, we have deforested and overgrazed areas that have led to soil loss, created saharazation and laterization, and altered hydrology and climatic patterns. An appraisal of these processess in terms of how better management can counteract them, and of how improved crop, range, and forest management can benefit agriculture, would facilitate a better estimate of the long-term costs or benefits. In addition, we have attempted to describe the current gaps of information that we believe deserve further scientific inquiry. The elimination of these gaps will broaden the base for future judgments.

The long-term ecological effects of the use of herbicides is difficult to predict. Herbicides differ from other types of vegetation-control agents in that they enter into biological systems, are selective in their effects, and have some degree of persistence. They have an advantage from an economic standpoint because they can be used to treat large areas selectively at low cost.

We have critically examined over 1,500 pieces of scientific literature, and supplemented these sources with information obtained in personal interviews and telephone conversations with over 140 knowledgeable people. We have obtained the most current information from government agencies, universities, private organizations and the chemical industry.

This preliminary assessment shows that the task of defining the ecological consequences of herbicide use is enormous. What we have done, in brief, is this: we have established a partial basis for an intelligent, objective evaluation of what is happening when sectors of our environment are exposed to herbicides. We hope that this assessment will stimulate the conducting of a deeper and more penetrating study, based on the additional research that is needed to close the knowledge gaps. Only one generation has passed since chemical herbicides began to be widely used. Within the last eight years the treatment of huge areas with potent chemical control agents has become a practical reality. To our knowledge no articles or books have been addressed to the subject of long-term ecological effects of herbicides, integrated with studies of flora and fauna, rangeland, forests, other nonagricultural lands, waterways, lakes and reservoirs. In the preparation of this review, it has been impressive that only two articles relating the full concept of ecology to two of our interests, weeds (Harper, 1957) and forests (Ovington, 1962), have been found. Harper points out that the most comprehensive food-chain study made so far involves only one weed, the ragwort; even here many links are missing. Ovington states, "Despite rapid and significant advances during the last decade, no reasonably comprehensive and balanced picture of the quantitative ecology of a single woodland ecosystem exists."

In the Chapters II through V the amounts and trends in the use of herbicides in noncrop areas are discussed. The military application of herbicides, with special reference to their current use in the Vietnam conflict, is reviewed. Military usage is of particular interest to the scientific community and the public; enormous amounts of herbicides are being applied to large areas, partly to render the movements of the enemy more conspicuous, partly to reduce his food resources; and the daily press has carried many stories on this subject. On the other hand, less well known to the general public are the large amounts of these same chemicals that are currently being used in this country, and the results of their experimental application as studied and recorded in scientific investigations. We have reviewed the application of herbicides to noncropland, forests, rangelands and aquatic ecosystems.

The effects of vegetation management and the resultant ecological consequences are discussed in Chapters VI through IX, and related to the herbicide applications previously mentioned. We have focused our attention on: the ecosystem, the relations of ecological action, the environmental relationships and the interactions of organisms within the community (i.e., food chains).

We have stressed the acute and chronic toxicity of herbicides, and emphasized the effects of herbicide usage in certain biologically sensitive areas: e.g., mutagenic effects, teratology, long-term pathology, reproduction, and behavioral changes. Another sensitive area of our inquiry concerns herbicide residues and the persistence of these residues in the environment, soil, water, fauna, crops, and other vegetation. We have examined the ecological effects and possible consequences of herbicides, defoliants and desiccants on the relationships of ecological action in our environment. Our emphasis in this respect has been given to the ecological effects on both the biota (i.e., food chains, faunal habitat and endangered species) and the abiotic processes (i.e., soil erosion, aggradation, laterization, hydrology, weather and climate).

In conclusion, we have attempted to summarize our findings as follows:

1. What judgments about the impact of herbicides on the ecology can be formed?

2. Which areas of inquiry are so inconclusive that reliable judgments cannot be made?

II. HERBICIDE PRODUCTION USAGE AND TRENDS

Throughout history men have modified their habitat by removing or controlling the surrounding vegetation--to provide greater security, better transportation, easier agriculture, forest exploitation, or to enhance the landscape (Becquerel, 1871, Marsh, 1885, and Dansereau, 1957). It has been estimated that more effort is devoted to the modification of vegetation than to any other human activity.

Fire, the ax, and browsing domestic animals have been the traditional means for clearing land, harvesting the forests and controlling unwanted brush. With these tools the deforestation of Europe, the cutting of the timberlands of the United States, and conversion of vast prairie lands to agriculture were accomplished--often accompanied by drastic disturbances in the ecology of the affected regions (Thomas, 1966; Darling and Milton, 1966).

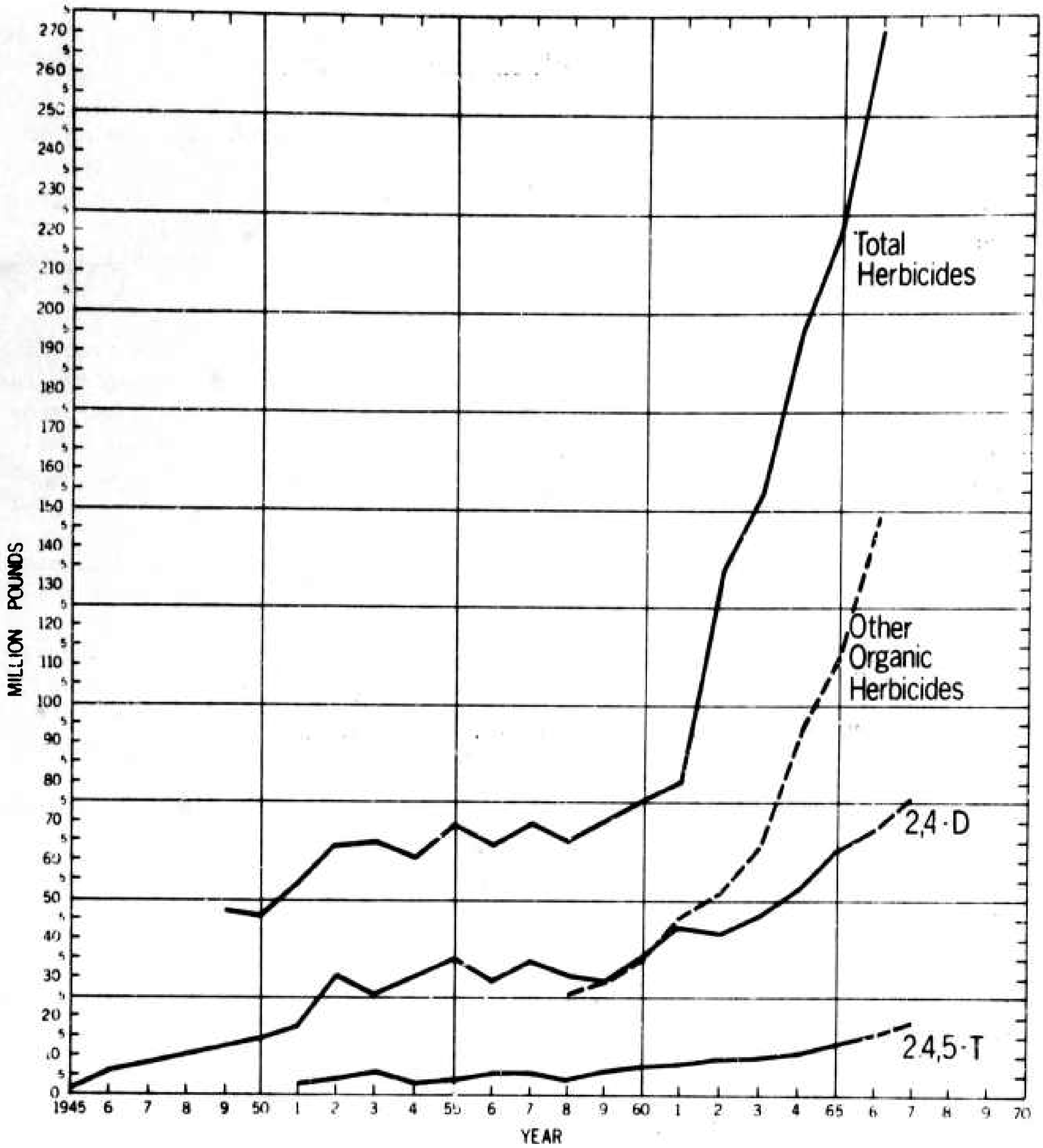
Within the last 20 years, herbicides have become a major tool used to control or destroy vegetation--rapidly, economically and over large areas.

The discovery and secret development of 2,4-D during World War II initiated a revolution in chemical weed control. In 1950, the estimated market for herbicides came to only $1.5-2.0 million, chiefly for borates, arsenites and other inorganic compounds. By 1965, this market had grown to over $211 million. In 1959, American farmers treated 53 million acres of acricultural land with herbicides at a cost of $129 million (including application costs) (USDA, ARS 34-23-1, 1965). Over 119.7 million acres of farmland was treated with herbicides in 1965, at a total cost of $493 million (Ennis, 1967). In a period of six years, herbicide usage more than doubled.

Without doubt, 2,4-D precipitated this phenomenal growth in herbicides, and stimulated the development of a host of new and potent plant control agents. By 1964, about 125 herbicide chemicals were marketed in some 8,000 different formulations.

Herbicides now represent the fastest growing segment of the pesticides industry. With 1966 production in the U. S. exceeding 220 million pounds, herbicides account for 26 percent of total pesticide tonnage, and for 44 percent of the value of all pesticide producers' sales (Shepard et al., 1967). Within a few years, chemicals for vegetation management will represent over half the total pesticide market value.

The pattern of ever-increasing use of herbicides is shown in Figure II-1. The older, inorganic herbicides and defoliants are declining in usage



Sources: Pesticide Review; U. S. Tariff Commission; Producers' Data.

Figure II-1 - U. S. Production of Herbicides by Class, 1945 - 1967.

as more selective, more effective and less hazardous agents have become available. Perhaps the most significant trend is that toward newer herbicides--such as picloram, bromacil, cacodylic acid, fenuron, or paraquat--each tailored to perform specific kinds of vegetation control (Table II-1).

TABLE II-1

U. S. PRODUCTION OF ORGANIC HERBICIDES
(1,000 pounds)

Year	2,4-D and 2,4,5-T Acids	Other Organic Herbicides
1958	34,622	25,295
1959	34,829	29,756
1960	42,522	33,201
1961	50,301	46,367
1962	51,366	51,913
1963	55,402	64,626
1964	65,148	93,909
1965	74,921	111,127
1966	83,671	149,352

Source: The Pesticide Review, 1958-1967.

Already the usage of these newer herbicides exceeds that of the phenoxy compounds which a few years ago dominated the field, and were the chemicals of choice for general weed and brush control. Any assessment of long-term effects of vegetation control must take into account these newer compounds which will become even more important in future control programs. Often less is known about the action and fate of newer chemicals than is known about 2,4-D; certainly less long-term field experience has been accumulated regarding effects of these new chemicals on the ecosystem.

Herbicides used in large quantities for vegetation control of non-croplands are listed in Table II-2, along with information regarding oral toxicity and some of the major applications of each herbicide.

The consumption of nearly 250 million pounds of herbicides gives ample testimony to man's intention to control and dominate the landscape. The overall purpose in using herbicides can be generalized as "weed control"--the

Table II-2

PRINCIPAL HERBICIDES USED IN NON-CROPLAND MANAGEMENT

Common Name	Chemical Name	Acute Oral Toxicity (LD_{50}) mg/kg[1]	Basic Chemical Used to Calculate Application Rate	Commercial Formulation[2]	Remarks
Amitrole	3-amino-1,2,4-triazole	5,000 (mice)	100 percent amitrole	WSP	Controls bermudagrass, Canada thistle, cattails, hoarycress, horsetail rush, leafy spurge, poison-ivy, poison-oak, prickly-ash, quackgrass, Russian knapweed, sedges, tules, white ash; apply in spray to foliage in spring; re-treat as needed.
Amitrole-T	3-amino-1,2,4-triazole plus ammonium thiocyanate		100 percent basic chemical	WML	Controls quackgrass, reed canarygrass, water-hyacinth; formulation more effective than amitrole alone.
Atrazine	2-chloro-4-ethylamino-6-isopropylamino-s-triazine	3,080	100 percent atrazine	WP	Controls germinating weed grasses and broadleaved weeds; use as preplanting soil-incorporated treatment to control quackgrass; chemical residues in soil may injure susceptible crops year after treatment.
Boron compounds (borax, sodium pentaborate, boron trioxide, anhydrous sodium biborate, and mixtures)			100 percent basic chemical	G or WSP	For soil sterilization to control deep-rooted perennial weeds and growth of all vegetation; addition of 2,4-D, sodium chlorate, benzoic acid, or substituted phenylurea herbicide to compounds will greatly reduce application rate needed for effective control.
Bromacil	5-bromo-3-sec-butyl-6-methyluracil	5,200	100 percent bromacil	WP	For control of germinating weed grasses and most herbaceous broadleaved weeds; especially effective on daisies and goldenrod; gives long-term control; persists in soils.
Cacodylic acid	dimethylarsinic acid	1,350 (mice)	Acid equivalent	WSS	Quickly kills most vegetation; used mainly to renovate turf.
Dalapon	2,2-dichloropropionic acid	6,590-8,120	Acid equivalent	WS	Use as spray to control growing annual weeds, bermudagrass, Johnsongrass, quackgrass, other perennial weeds, cattails, Phragmites; most effective in crops when applied in combination with tillage and cultural practices.
Diquat	6,7-dihydrodipyrido (1,2-a:2',1'-c) pyrazidiinium salt	400-500	Cation equivalent	WS, WSa	Controls certain aquatic weeds; is general contact herbicide for control of many established weeds; desiccant in harvesting certain crops; deactivated on contact with soil.
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea	3,400-7,500	100 percent diuron	G, WML, WP	Controls perennial grasses and annual broadleaved weeds.
DSMA	disodium methanearsonate	800-2,800	100 percent DSMA	G, WP, WS	General contact herbicide used as spot treatment to control many weeds in early stages of growth.
Endothall	7-oxabicyclo(2.2.1) heptane-2,3-dicarboxylic acid	35-120	100 percent salt of endothall	EC, G, WS WSa	Controls germinating weeds in certain crops and some submersed aquatic weeds; fish are tolerant to relatively high concentrations of disodium salts, but dimethylalkanolamine salts are toxic at concentrations of 0.5 ppmw.
Monuron	3-(p-chlorophenyl)-1,1-dimethylurea	3,400-7,500	100 percent monuron	G, WML, WP	Controls many germinating broadleaved weeds and weed grasses; use in certain row crops and as soil sterilant in noncrop areas.

TABLE II-2 (Concluded)

Common Name	Chemical Name	Acute Oral Toxicity (LD_{50}) mg/kg[1]	Basic Chemical Used to Calculate Application Rate	Commercial Formulation[2]	Remarks
MSMA	monosodium acid methanearsonate	700	100 percent MSMA	EC, WSa	Always use with surfactant since thorough coverage is extremely important; very useful for postemergence control of young crabgrass in turf and for control of dallisgrass.
Paraquat	1,1'-dimethyl-4,4'-bipyridinium salt	157	Cation equivalent	WML, WS	Use as general contact weedkiller or directed sprays on young weeds.
Picloram	4-amino-3,5,6-trichloropicolinic acid	8,200	Acid equivalent	G, WSC	Controls several brush species; use on noncropland including utility rights-of-way and industrial storage areas
Silvex	2-(2,4,5-trichlorophenoxy)propionic acid	375-1,200	Acid equivalent	EC, G, WSa	Controls young broadleaved weeds, including chickweed, curly dock, henbit, lambsquarters.
Simazine	2-chloro-4,6-bis (ethylamino)-s-triazine	5,000	100 percent simazine	WP	Controls germinating annual broadleaved weeds and weed grasses; controls vegetation on noncropland; long residual action.
Sodium arsenite		10-50	100 percent sodium arsenite	WML, WP, WSC	Controls submersed aquatic weeds; also use as soil sterilant to control all vegetation; fish not injured at concentrations up to 10 ppmw; as soil sterilant, soil unproductive for 1-4 years; do not treat areas frequented by livestock with this herbicide.
Sodium chlorate		7,000	100 percent basic chemical	WSP,WSS	Use as soil sterilant to control all vegetation; leaves soil unproductive 1-4 years depending on precipitation, temperature, soil type; sandy soils of humid areas require higher applications than heavy soils of arid regions; toxicity persists longer in arid regions.
TCA	trichloroacetic acid	5,000	Acid equivalent	WS, WSa, WSP	Controls many germinating and established perennial grasses, broadleaved weeds including johnsongrass, quackgrass; residual toxicity may persist year or longer at high rates.
2,4,6-TBA	2,3,6-trichlorobenzoic acid	1,644	Acid equivalent	EC, G, OS, WML, WSa	Preemergence and postemergence treatments for control of bindweed, quackgrass, wild garlic, some perennial broadleaved herbaceous weeds; brush treatment may prevent crop production for 1-3 years.
2,4-D	2,4-dichlorophenoxyacetic acid	375-1,200	do	EC, WML, WS, WSa	Controls many germinating and established annual broadleaved weeds including lambsquarters, mustard, pigweed; do not use volatile esters near susceptible plants such as cotton, flowers, grapes, ornamentals, tomatoes.
2,4,5-T	2,4,5-trichlorophenoxyacetic acid	375-1,200	do	EC, WML, WS, WSa	Broadleaved weeds; do not use volatile esters near such susceptible plants as cotton, flowers, grapes, ornamentals, tomatoes.

1/ Milligrams of herbicide per kilogram of body weight of rats or other specified animal.

2/ EC, emulsifiable concentrate; G, granular base; oil, oil soluble; OS, soluble in organic solvents; WML, water-miscible liquid; WP, wettable powder; WS, water soluble; WSa, water-soluble salt; WSC, water-soluble concentrate; WSP, water-soluble powder; WSS, water-soluble soild.

Agriculture Handbook 332, U.S. Department of Agriculture (1967) suppression or removal of vegetation which grows where it interferes with man's intended use of the land.*

When used for vegetation control, herbicides kill or suppress some species of plants, while leaving others unaffected. Thus, when dealing with a relatively stable plant community, herbicidal control, like other methods of control such as fire, mechanical removal, or biological control, results in three primary ecological shifts:

(1) Simplification of the plant community,

(2) Setting the community back to a subclimax or unstable condition in which some ecological niches are vacant, and

(3) Altering or reducing competition within the treated area.

These are the primary and direct effects of the herbicide, quite independent of any side effects due to residues or toxicity.

The possibility of ecological repercussions from herbicide use depends more on how these chemicals are used than on the total quantity of herbicides produced and used. Ultimately, the avoidance of biological problems and side effects is dependent upon the degree of ecological knowledge, management skill, and social responsibility of those who employ herbicidal chemicals. In any particular application, the long-term consequences also depend upon:

(1) The purpose or objectives of herbicide use,

(2) The environment to which herbicides are applied,

(3) The chemical agent used,

(4) The dosage rate or frequency of treatment, and

(5) The means of application and control of placement.

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* Moore (1954) defined a weed as: "A plant which interferes with man's utilization of land for a specific purpose," and Stearn (1956) comments: "Taken as a whole, weeds are not so much a botanical as a human psycological category within the plant kingdom, for a weed is simply a plant which in a particular place at a particular time arouses human dislike and attempts are made at its eradication or control, usually because it competes with more desirable plants, sometimes because it serves as a host to their pests and diseases, or is unpalatable or dangerous to domestic beasts."

Important Classes of Herbicide Use

In addition to use on croplands, herbicides are employed for a remarkable variety of purposes--improving wildlife habitat, killing forest stands prior to cutting, limiting the spread of disease vectors, increasing the grazing capacity of rangeland, maintaining industrial rights-of-way and increasing the water yield or run-off of watersheds into reservoirs--to name a few.

Agricultural uses on crops consumes more than half the herbicides sold in the U. S. Noncrop applications on farms, together with nonagricultural uses, account for the balance of domestic consumption. The estimated distribution of herbicides by end use for 1965 was:

Total production, organic herbicides	220,003,000 lb.
U. S. producers sales	182,869,000 lb.
Net exports (approximate)	32,000,000 lb.
U. S. Consumption	150,869,000 lb.
Sales to farmers (59%)	89,000,000 lb.
Farm use on croplands (approximately 88%)	78,400,000 lb.
Farm use on noncroplands (12%)	10,600,000 lb.
Nonfarm uses	61,869,000 lb.

While agricultural uses on corn, cotton, rice, vegetables and orchard crops, account for most of the acreage treated in the U. S., herbicides are applied to substantial areas of noncropland.

Noncrop uses usually require more pounds of herbicide per acre. In 1962, for example, the average cost per acre for treating noncropland was $23.18, almost ten times the $2.28 required for corn, and over twice as much as the $9.09 spent treating an acre of vegetables (USDA ARS-34-23-1, 1965).

This report concentrates on various applications of phytotoxic chemicals to wild areas, or to relatively stable, undisturbed plant communities. Often such treatments involve overall spraying of vegetation. When chemicals are applied to these natural plant associations, opportunity is afforded to observe the primary and secondary effects, and to follow the direct and indirect ecological shifts or interactions resulting from herbicide use.

Subsequent sections of this report focus in greater detail on several major fields of vegetation control such as commercial forestry, brush control on range and grazing land, maintenance of industrial rights of way and aquatic weed control.

The noncropland uses of herbicides can be expected to increase considerably, both in extent of acreage treated, and in consumption of herbicides. According to estimates reported at the 1962 Northeast Weed Control Conference:

> "Weed control of some type is required annually in the United States on about 140 million acres of row crops (weeded intensively), about 230 million acres of drilled crops (with moderate weeding), one billion acres in hay, pasture and range (with limited weed control), 30 million acres in connection with railroads and highways, and about 33 million single-family homes requiring some weed control."

Few realistic estimates exist of the extent to which herbicides are actually used on noncultivated land. One recent survey showed that during 1965 the following areas are known to have received herbicide treatments in agriculture:*

Rangeland	3.2 million acres
Permanent Pasture	6.7 million acres
Lawns and Turf	1.1 million acres
Other Noncroplands	3.3 million acres
Forestland	117 thousand acres
Aquatic Sites	84 thousand acres

The approximate areas of various types of land which may require control of vegetation are shown in Table II-3. Because some classifications overlap, the areas shown do not add up to the total land area of the United States.

Minnesota maintains records of all applications of herbicides including several important classes of noncrop usage. The amount of herbicides used, and the number of acres treated in Minnesota, represent substantial totals despite the fact that Minnesota does not spray as extensively as Texas for brush c ntrol on range; that commercial forestry use of herbicides is less than in other regions; and that the aquatic weed control problem is less severe than along the Gulf Coast. Nearly 40 percent of the total road mileage in Minnesota receives chemical treatment along the roadside. This compares with a nationwide average of perhaps 10 to 15 percent. Within the last few years there has been a marked increase in the spraying of utility rights-of-way (Table II-4).

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* Ennis, W. B., Unpublished data, released by USDA to DoD, for administrative use only.

TABLE II-3

LAND UTILIZATION, 1965

Total Land Area--48 States 1,934,600,000

Land Type		Land Use (000) Acres
Cropland and Cropland Pasture		457,000
Permanent Grassland Pasture		463,900
Grazing Land and Open Range		417,600
Forest and Woodland ("commercial")		501,900
Forest in farms	(162,300)*	
Forest not in farms	(339,600)	
State and National Parks		22,000
Military Areas		17,900
Wildlife Refuge, Waterfowl Reserve, Game Management Areas		17,000
Inland Water Areas		32,600
Ponds	(2,000)	
Large impoundments	(19,500)	
Streams	(5,500)	
Irrigation ditches	(400)	
Drainage ditches	(200)	
Wetlands, bogs, swamps	(5,000)	
Industrial Rights-of-Way		11,800
Railroad	(1,300)	
Electric power	(7,049)	
Telephone and other	(3,500)	
Roadside and Highway		14,950
Urban and Built-up Areas		53,000
Private lawns and turf	(16,000)	
Industrial, municipal, other turf	(10,000)	
Desert, Dunes, Barrens, Wildland		26,950

* Figures in parentheses are estimated breakdowns within each category. Because certain categories overlap, totals are not strictly additive.

TABLE II-4

NONCROPLAND USE OF HERBICIDES, STATE OF MINNESOTA

Year	Soil Sterilizing Compounds (lb.)	Pasture Meadow & Brushland Sprayed (Acres)	Miles of Highway and Road Sprayed: Total Roads and Highways	State Trunk Highways	County & State Aid Roads	Township Roads	Miles of: Telephone Power Line Right-of-Way	Railroad Right-of-Way	Drainage Ditches
1950	911,207	183,738	32,853	4,541	19,790	8,522	2,565	--	--
1951	839,309	112,371	24,859	3,432	15,207	6,220	1,663	4,390	1,071
1952	958,048	212,445	29,405	4,645	16,923	7,837	4,838	4,341	1,827
1953	1,380,026	172,631	36,133	5,777	20,275	10,081	4,508	2,896	2,201
1954	1,659,993	149,888	41,949	6,143	22,422	13,384	7,521	3,388	1,795
1955	1,457,669	157,205	45,412	8,071	23,224	14,117	6,294	3,842	2,650
1956	971,755	166,530	45,105	8,182	23,276	13,647	4,579	4,184	3,436
1957	688,736	172,295	48,107	8,603	23,921	15,583	6,767	3,780	2,485
1958	788,247	162,244	54,157	8,499	27,424	18,234	7,127	4,194	3,027
1959	499,896	158,141	59,091	9,298	29,203	20,590	6,056	4,000	3,942
1960	476,589	173,194	55,495	8,359	28,275	18,861	7,605	4,473	2,843
1961	467,997	204,500	57,288	9,265	28,063	19,960	7,314	4,198	3,548
1962	384,719	385,166	55,554	8,778	28,008	18,768	5,820	4,329	3,007
1963	335,297	166,173	57,953	10,741	29,323	17,889	7,417	4,467	3,624
1964		163,847	48,442	8,026	25,015	15,401	11,822	3,865	3,212
1965		147,145	48,475	7,305	25,221	15,949	13,772	4,066	3,196
1966		181,082	50,458	7,903	26,975	15,580	22,168	4,140	4,500
1966 Data Converted to Acres for ease of comparison:			257,000A	(79,000A) at 10A/Mi	(130,000A) at 5A/Mi	(48,000A) at 3A/Mi	220,000A at 10A/Mi	24,500A at 6A/Mi	9,000A at 2A/Mi

Source: State of Minnesota, Department of Agriculture, Division of Agronomy Services, Section of Weed Control (Compilation of Years, 1950-1966).

Herbicide Shortage

Shortages of key herbicides began to develop in 1967 throughout the southern and midwestern markets. Most critical are the two widely used weed killers, 2,4-D and 2,4,5-T. Both are used also as defoliants in Vietnam. Military demand for 2,4,5-T is so great that the Government has pre-empted all 2,4,5-T production until further notice.

The U.S. capacity for 2,4-D (acid basis) is about 80 million pounds per year; and for 2,4,5-T is 20 million pounds. Estimated defense requirements are 80 million pounds of each compound. Normal agricultural requirements in the U.S. for 1966 were 57 million pounds, and 7.5 million pounds, respectively (Chemical Week, 1967).

Shortages of the widely used chlorophenoxy compounds have, in turn, made supplies of other herbicides tight. Atrazine, Randox, Tordon 101, Amiben, Herban, and Planavin have been placed on allocation by their manufacturers or are on priority distribution.

A major electric power utility, which sprays 14,300 miles of its rights-of-way, has drastically cut its control operations this year. One of the largest forest land management companies had to cease herbicide spraying: "No spraying this year. . . .2,4-D and 2,4,5-T have gone to war."

One question which was posed during the course of gathering data regarding possible long-term consequences of herbicide use is rather thought provoking: "What are the long-term ecological consequences of not using modern chemical herbicides?" Because the present shortage is expected to be temporary no attempt has been made to estimate either economic losses due to curtailed weed control activities, or the ecological effects of reduced herbicide spraying.

III. HERBICIDE APPLICATION ON VARIOUS LAND AREAS

In the previous section, statistical information has been presented concerning the application of herbicides to various land areas. In this section, the usage of herbicides on: (a) crops, (b) noncroplands, (c) forests and (d) rangelands will be reviewed. Each one of these sectors will present the background, the vegetation problems that need to be met, development of herbicidal use, and the methods and rates of application. Some attention will be given to the costs of application of the herbicides under various circumstances. Each one of the sections will include a discussion of some of the ecological aspects of the particular type of land area as related to herbidide usage.

We have not reviewed in any depth the application of herbicides to croplands. It is conceded that the role of herbicides on cropland is of great economic and social importance. However, the ecological consequences of applying herbicides to crop mono-culture is minimal when related to the ecological consequences involved in their application to noncroplands, forests and range.

The noncropland discussion will be limited to the status of vegetation control along power, communication, roadway, railroad and pipeline rights-of-way. Firebreaks and industrial plant needs will be touched upon.

In the section on forests, we deal with utilization of herbicides in forests nurseries, plant-site preparation, the release of desired species and timber stand improvement.

Within the section on rangelands, mechanical, burning, biological and chemical methods of vegetation control will be discussed.

A. Herbicides for Croplands

By far the most important application of herbicides--currently accounting for half of all consumption--is weed control in crops. U. S. farmers spent nearly $500 million in 1966 treating 119 million acres (Ennis, 1967); or 26% of all land planted with crops. Over 43% of all corn acreage, 25% of small grains, and 29% of all cotton acreage in 1966 received herbicide treatment (Sheppard, 1967). Herbicides have become an indispensable tool of agriculture.

Two vital reasons dictate this rapidly increasing use of chemical weed control agents:

1. Herbicides increase the farmer's profit (for rice the gain can be as much as $40 per acre).

2. Herbicides allow more food to be raised on each acre, with less labor.

The acreage devoted to crops is decreasing in the United States. By 1975, more than 20 million acres will go out of private agriculture; the net loss is about 1 million acres per year. Most of this land will go into "built-up areas"; there will also be important shifts to outdoor recreation, wildlife habitat, and to highways, airports and industry (USDA, 1962). Farm labor continues to decline. Nonetheless, modern technology--machines, chemicals and management methods--continue to increase the per-acre yields from croplands.

In foreign agriculture, especially in the tropics, the need for herbicides is critical. Extensive programs of land improvement and land conversion to crop production are essential to feeding fast-rising populations. "In tropical agriculture, weeds are a major factor limiting crop production. The number and diversity of weed problems are much greater than under temperate zone conditions, and weeds present problems over a much longer period of the year. Yield increases resulting from improved weed control alone may be sufficient to more than solve current food shortages." (Furtick, 1967). In Japan, for example, nearly 45% of the rice crop is treated with 2,4-D, increasing yields as much as fourfold. Although the role of herbicides on croplands is conceded to be of great economic and social importance, little attention will be given throughout the balance of this report to use on cultivated crops.

The ecological consequences of applying herbicides to a crop-monoculture, such as a wheat field, are minimal. Good cropland in continuous production represents an artificially stabilized ecology. Most long-term effects are wiped out after the crop has been harvested, and the land prepared to grow next season's crop. The economic stake of the farmer provides strong incentives to exercise care in choice of herbicide and control of application factors. This care tends to minimize side effects such as residues or pollution.

Any assessment of herbicide use on crops must be based, we believe, chiefly on economic and social grounds, and not on long-term ecological effects on the environment.

B. Herbicides for Noncroplands

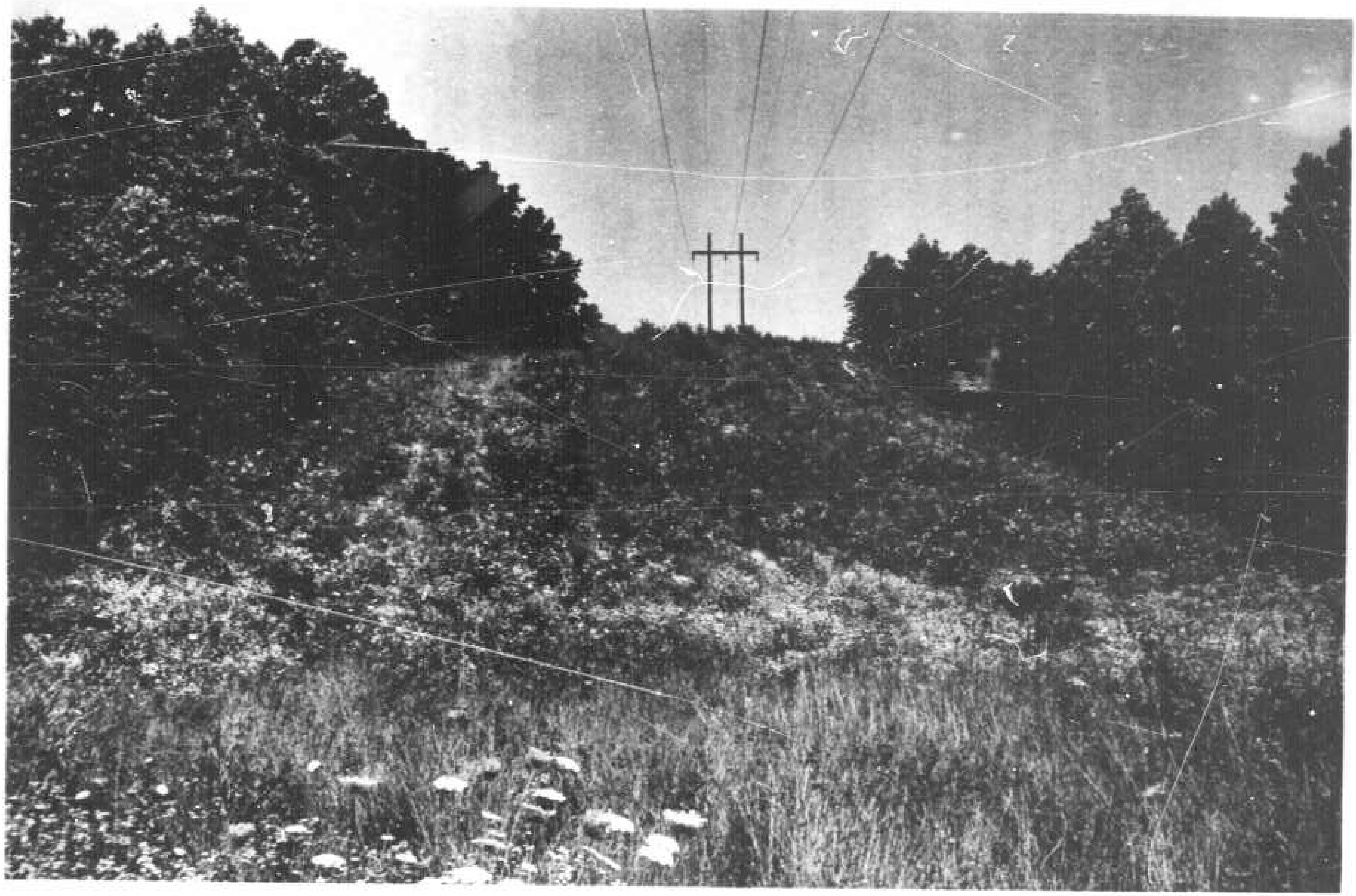
It is estimated that in 1965 cropland and cropland pasture totaled 457 million acres, of which about 120 million were treated with herbicides. The noncropland areas approach one billion acres exclusive of desert, barrens, wildlands and built-up areas. The use of chemicals on noncropland began when man first applied salt to the earth to kill the vegetation. Sodium arsenite was used on water hyacinth in 1902, copper sulfate was used as a herbicide on algae in 1904. In 1919, George Gray of California, discovered the translocation of arsenic in wild morning glories. Sodium chlorate was introduced for killing weeds by application in soil in 1925. A decade later, France exported sodium dinitrocresylate to America as the first selective organic weed killer. Rapid acceleration of the use of chemical herbicides followed the announcement of the discovery of 2,4-D in 1944 and its use in 1945. After the advent of 2,4-D, the development of other organic chemicals and dozens of formulations proceeded at a rapid pace.

Utility Rights-of-Ways

In 1958, Egler stated, "The rights-of-way of the utility corporations alone comprise an acreage greater than all six New England states combined." According to recent figures, power, communication, railroad, highway and roadways comprise about 26,000,000 acres.

Vegetation control along rights-of-way is important to a large segment of the population. The utility corporations, land owners, chemical manufacturers, spray and line clearance contractors and the public, are involved. Each group is obviously concerned for different reasons (economic and esthetic). As a result of this widespread interest, vegetation management of rights-of-way and roadsides is becoming an integrated division of land management (Figure III-B-1).

Until recent years, mechanical methods were the only effective means of controlling brush, and even now some utility rights-of-way are maintained by mechanical methods. The hand method requires large crews using brush hooks, axes, and power saws for periodic clearing of brush, and it is usually necessary to repeat the operation every two years. Because of the rising cost of labor, the hand method has become increasingly prohibitive; as a result, many improved mechanical devices have evolved. In general, these devices, such as rotary brush cutters and the large self-propelled machines, having a huge metal drum with flails attached, are somewhat limited in their use, especially in rocky or mountainous terrain. A more recent mechanical device, the hand power saw,



Courtesy Tennessee Valley Authority

Figure III-B-1 - Brush Control Along the Rights-of-Way is an effective and practical approach to underbrush control in rough terrain conditions. In large integrated rights-of-way maintenance programs there is a place for the mechanical along with the newer method of chemical brush control (Figure III-B-2).

Chemical sprays of vegetation along rights-of-way may be categorized as follows:

Foliar treatment: Foliar treatment is usually used for a woody plant control. It has importance as a primary spray in the maintenance of rights-of-way. It has its greatest effectiveness in the growing season (Spring) and, to be effective, it must thoroughly wet the entire vegetation. Foliar sprays make way for follow-up treatment by modified basal sprays.

Foliar stem sprays: Foliar stem sprays are usually more drastic in their action than foliar sprays. This is accomplished by addition of oil which increases bark penetration.

Basal spray treatment: Basal spray treatments are usually applied over five to 10 years. This is a more selective-type treatment and allows the selection of certain desired plant species.

Dormant stem treatment: Dormant stem treatment is considered an all-year-round operation. It is used in areas where species are prolific that produce longer root systems.

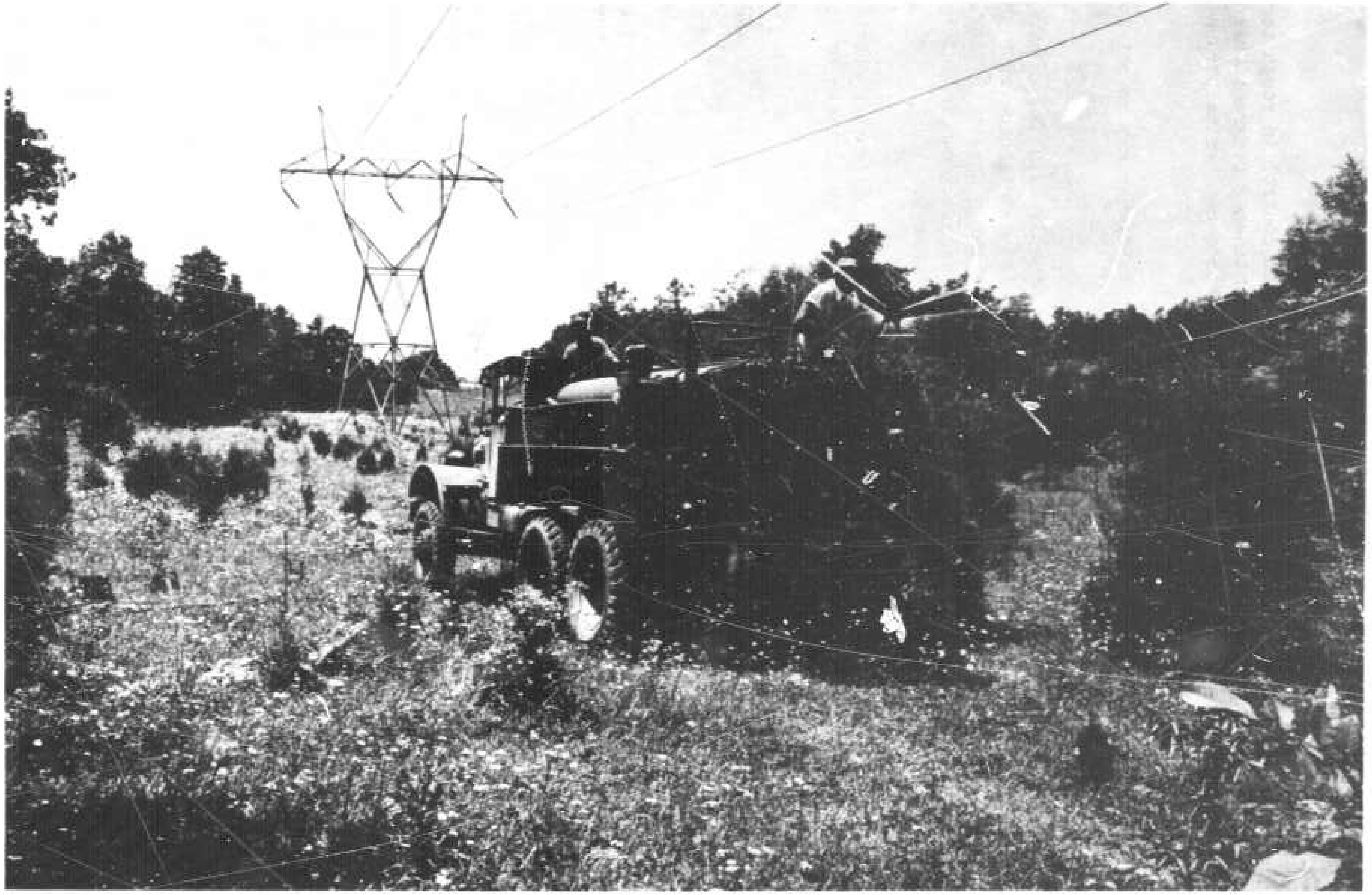
Frill and injection technique: If for some reason it is not desirable to cut trees and treat the stumps, the frill or the injection technique may be used. To prepare a tree for the frill treatment, a cut is made into the sap wood girdling the tree and the appropriate chemicals are introduced into the incision. In the injection technique, the herbicide is injected directly into the heartwood near the base of the tree.

Basal soil treatment: The basal soil treatment is usually accomplished by dry, powdered or pelleted herbicides that are scattered over the soil surface above the root systems. Rainfall moves the chemical down into the roots.

Examples of types of herbicides used in rights-of-way vegetation control are as follows:

1. Woody plants

   A. Chlorophenoxy acids
   B. Ammonium sulphamate
   C. Fenuron



Courtesy Dow Chemical Company

Figure III-B-2 - Spraying High Line Right-of-Way with Mobile Spray Unit

D. Picloram
E. 2,3,6-TBA

2. Mixed herbacious broad-leafed and grassy weed

   A. Amitrole
   B. Ammonium sulphamate
   C. Borate sodium
   D. Bromacil
   E. Diuron
   F. Monuron
   G. Paraquat
   H. Simazine
   I. Atrazine

3. Broad-leafed herbacious weeds--selective control and desirable grasses

   A. Chlorophenoxy acids
   B. PBA
   C. Picloram
   D. 2,3,6-TBA

4. Weedy grasses where control of broad-leaf weeds is not necessary

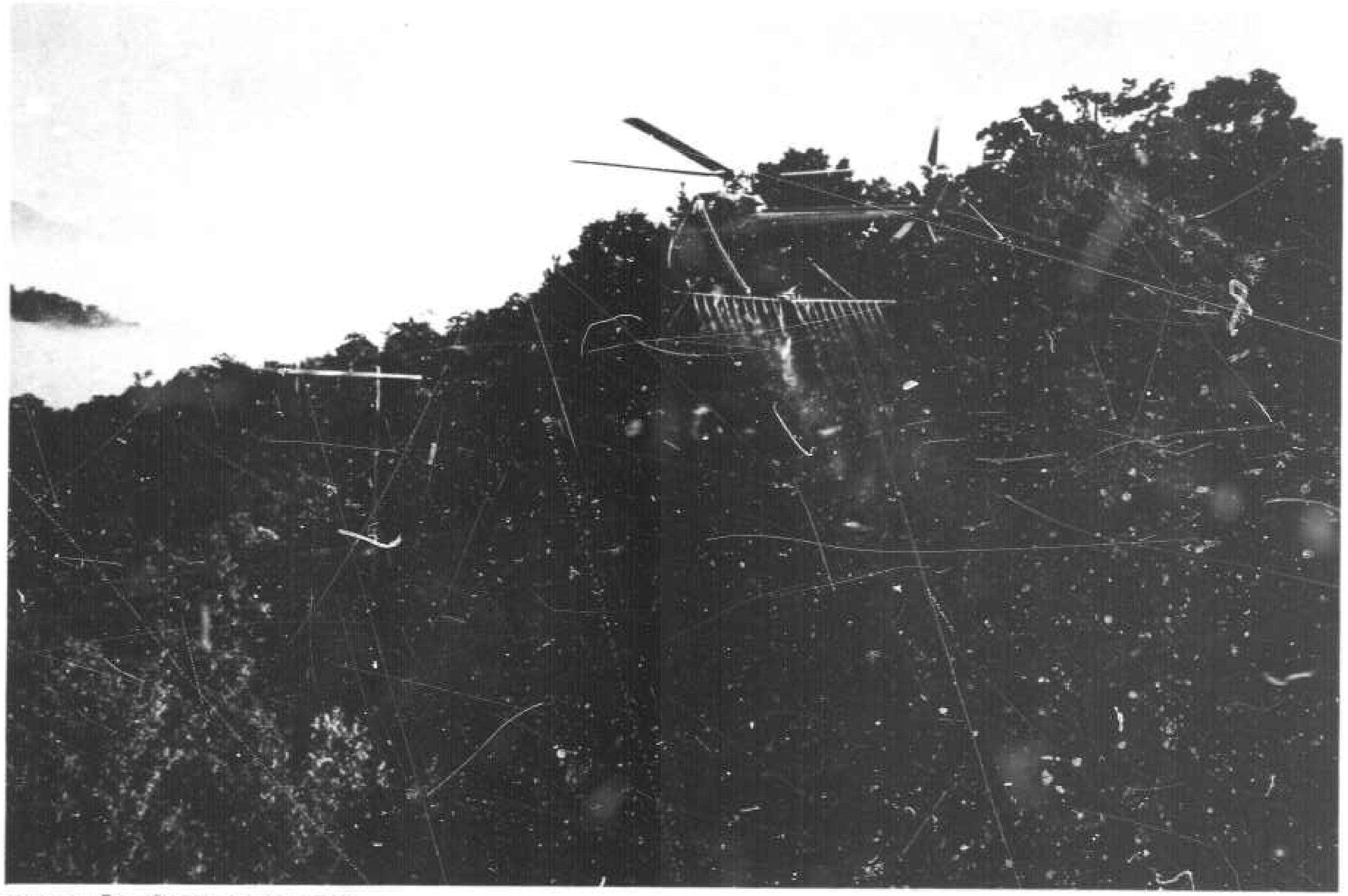
   A. Aromatic oils
   B. Dalapon
   C. DSMA
   D. MSMA
   E. Sodium TCA
   F. Amitrole

Reference may be made to Table A-4 in the Appendix which indicates the pounds of active ingredient recommended per acre for the various herbicides listed under the above classifications. The information above and the data in Table A-4 have been taken from USDA Agriculture Handbook, 332, pp. 51-54.

The maintenance of rights-of-way of large utility transmission systems, some of which are in excess of 14,000 to 17,000 miles in length, presents a formidable problem. One of the most economical approaches for herbicide application is the use of fixed wing aircraft or helicopters (Figures III-F-3 and -4). Helicopter spraying by the Ontario Hydro started in 1951. Helicopters have an advantage over fixed wing aircraft in that they are more maneuverable. The major restriction on aircraft spraying is suitable weather. Some operators with liquid spray units do not fly if the wind velocity is over

Courtesy Dow Chemical Company

Figure III-B-3 - Helicopter Spraying Power Transmission Rights-of-Way



Courtesy Dow Chemical Company

Figure III-B-4 - Aerial Spraying of Utility Right-of-Way

5 miles/hr. Some operators feel that helicopters are more satisfactory than fixed wing aircraft because a lower flying speed is possible and greater maneuverability of the helicopter contributes to more accurate placement of the spray pattern.

Some examples of foliar spray operations, the chemicals and application rates as related to their effectiveness follow.

Grundy and Bennett (1960) have pointed out that 70 to 90% top-kill is obtained on poplar, birch, willow and tag alder with application of 4 lb. of acid equivalent per 7 gal of a formulation of 2,4-D and 2,4,5-T in oil. The conifers, balsam, fir and spruce are resistant to 2,4-D and 2,4,5-T sprays. Their work with TCA was satisfactory. Using rates of about 26 lb. of acid equivalent per acre, gave good control over parts of the right-of-way. They used two 11-ft booms for application on 100-ft rights-of-way. Control was confined in most instances to a strip on each side of the power line directly under the path of the helicopter. In terms of cost in 1958, helicopter spraying on 5,798 acres averaged less than $22 per acre whereas foliar spray with ground equipment averaged about $26 per acre on 22,358 acres.

Suggitt and Winter (1965) and Suggitt (1965) described some of the problems of handling drift from aerial spraying. This phenomenon is especially a problem when spraying has to be done near cultivated areas. They have determined the desirable median droplet size and the amount of spray needed (8 to 12 gal/acre) to penetrate brush foliage of heights of 6 to 10 ft.

Table III-B-1 contains their data for droplet coverage in relation to the diameter of droplets (μ). They found the most desirable droplet size to be between 300 to 500 μ.

Studies (Mann, 1960) have been made of the use of invert or thickened chemicals to reduce the problem of drift. Greater control over drift allows the helicopter to fly 10 miles/hr, which increases flying time per day.

Pellets are another approach to the drift problem in aerial spraying (Mann, 1966). Some of the advantages of using pellets are as follows: (1) material can be applied in winds up to 12 miles/hr; (2) elimination of brown-out; (3) the material is nonvolatile; and (4) helicopter can be used for pellet application before the foliage spray season. The disadvantages are: (1) cost; (2) there is some tendency to kill brush off of the rights-of-way because of the extension of the lateral root systems; and (3) adequate rainfall is needed to move the material into the ground.

TABLE III-B-1

DROPLET COVERAGE ON A FLAT SURFACE FOR AN APPLICATION RATE OF 4 GAL/ACRE

Diameter of Spray Droplets (μ)	Number/Sq Inch	Distance Between Droplets (inches)	Description of Falling Spray
1000	4.6	0.47	Moderate rain
500	37.0	0.16	Light rain
200	570.0	0.043	Drizzle
100	4600.0	0.015	Mist

According to some tests made by TVA (Mann, 1966) the materials (Dybar, Urba and Tordon 10K) are highly satisfactory for brush control at various rates. However, a continued evaluation will be required to determine an effective rate for various species.

A problem occurred on the TVA system in that many tracts of land or farms were cleared several months before line construction was completed (Mann, 1965). The interval resulted in a medium to dense stand of brush ranging from 6 to 20 ft in height on the right-of-way at the time the line was energized. The stem count in the area ranged from about 5,000 to 10,000/acre and consisted of ash, cedars, dogwood, hickory, maples, oaks, persimmons, pine, poplar, sassafras, sourwood and sumac. They treated about 38 acres with 3 gal/acre of 2,4,5-T esters containing 4 lb. of acid equivalent per gallon in 97 gal of diesel oil. The application was made by knapsack sprayers because of the rough mountainous terrain. They applied approximately 2,969 gal of mixture and the average cost was about $57 an acre. A stem count was made in the area 31 months after application. It was found about 81% of the stumps had been killed. In comparing this type of treatment with the foliage treatment, the results would be about equal. However, the cost of foliage treatment would be approximately $72 an acre as compared to $57 an acre for stump treatment. The stump-treated area did not require treatment until after three full growing seasons, and then it was foliage treated with ammate near crops and with esters in other areas. A summary of the cost of stump treatments performed since the program was initiated in 1957 is as follows (Mann, 1963).

Calendar Years	Number of Acres	Cost Per Acre
1957	3,562	$60
1958	1,933	62
1959	1,712	63
1960	1,698	65
1961	2,239	69
1962	1,374	67
Total Acres	12,518	
Average Cost an Acre		65

The cost breakdown was as follows: labor, 40%; transportation, 10%; and materials, 50%.

After foliar applications it is usually necessary within a few years to use a different approach to brush control in order to eliminate the more resistant species (for example, ash, maple and elm). Usually this is done by basal or dormant treatment. Also, the dormant treatment is being used by certain large utilities for "catching skips" near crops. Modern brush control methods by utility rights-of-way maintenance people is fast becoming a science. A number of them determine the proper spraying method and herbicide selection by making surveys of their rights-of-way to learn the species present, their height, and stem count or density. It has been calculated (Mann and Aldred, 1964) that the stem count for basal or dormant application, to be economically feasible, should average 4,000 stems/acre or less. One formulation for typical dormant spraying would consist of 3 gal of 2,4,5-T esters (4 lb. acid/gal) and 97 lb. of diesel oil. Application is made to the brush within a foot of the ground line, permitting the mixture to run down and thoroughly wet the root collar. Listed below are the acres treated by the dormant method with the cost per acre for fiscal years 1956 to 1963 for the Tennessee Valley Authority (Mann and Aldred, 1964).

F.Y.	Acres	Cost/Acre	F.Y.	Acres	Cost/Acre
1956	1,885	$62	1960	1,976	$63
1957	1,663	96	1961	1,854	70
1958	3,481	85	1962	1,287	71
1959	1,153	63	1963	3,096	64

In many areas, in this country and Canada, where utility rights-of-way pass through pine forests, conifers become a serious maintenance problem. Herbicides 2,4-D and 2,4,5-T are effective in controlling deciduous woody growth, but have little effect on conifers. In fact, 2,4,5-T is the herbicide of choice for pine release. The conifers grow much more rapidly than normal when the competition is reduced for light, moisture and nutrients, and they become a dominant vegetation in rights-of-ways. Oil-borne sprays, containing 2,4-D and 2,4,5-T, have been used for conifer control in the northeastern states. Bennett (1957) points out that the extensive use of oil for spraying under Canadian conditions is limited mainly by the cost and the difficulty of transporting the required oil volume into remote areas. This investigator evaluated the following herbicides. 2,3,6-TBA, monuron, TCA, dalapon, ammonium sulphamate, ATA, erbon, sodium chlorate, 2,4,5-T and 2,4-D and their various esters, and 4-CPA. These tests were made on 160-acre plots comprising more than 6,000 tag stems. Effective control of conifer, balsam, fir and black spruce was obtained with water-borne sprays of monuron, 2,3,6-TBA, silvex, TCA, and dalapon applied during the growing season. With the exception of treatments incorporating oil and oil-water carrier, no treatment gave satisfactory control during April or October. TCA (4 - 6 lb. AE) and 2,3,6-TBA (8 - 10 lb. AE) were considered the most suitable materials for extensive use.

Telephone lines are special types of rights-of-ways in that they are usually associated with roadways. The maintenance of the line in terms of vegetation control involves a wide degree of planning. For instance, the American Telephone and Telegraph Company operations are from coast to coast. Coffey (1955) indicates that the regional cutting intervals are five - 10 years in the Rocky Mountain states, three - five years in the Southwest, and one, two or three years in most of the other regions of the United States. Coffey (1955) has outlined the planning and programming for conversion from brush cutting of rights-of-ways to chemical control. He indicates that good management requires the developing of a long-range plan for chemical control. He believes that the major steps in planning are (1) brush inventory; (2) job specifications; (3) material supervision; and (4) field inspection.

The following inventory should be made: the location and quantity, the growth conditions, the width of right-of-way to be treated in various sections, the location of access roads, ditch crossing, fence openings, location of accessible water for spraying foliage, and what crops are grown in the section that might limit the method or time of spraying. The salient considerations under job specifications are: coverage, timing and materials. They utilize two treatments, foliage and basal spray. As a final yardstick for determining the results, they measure costs and there are many ways to do it. Hand-cutting versus spraying on a short-term basis indicates that hand-cutting costs are cheaper. A comparison of the costs on a long term were as follows

Plot	1	2	3
Acres	73	36.7	112
Year	1946-54	1945-54	1948-53
Estimated Hand-Cutting Costs	$9,600	$6,608	$19,488
Chemical Spray Costs	$3,544	$4,774	$6,932

The Consumer Power Company Forestry Department has reported data on manual versus chemical cost of vegetation control of power transmission lines from 1948 to 1965. Table III-B-2 indicates that the amount of manual labor has been reduced appreciably over the years.

TABLE III-B-2

COST FIGURES FOR MAINTENANCE OF POWER TRANSMISSION AND SUBTRANSMISSION LINES MANUAL AND CHEMICAL

(Total Annual Cost Per Mile)

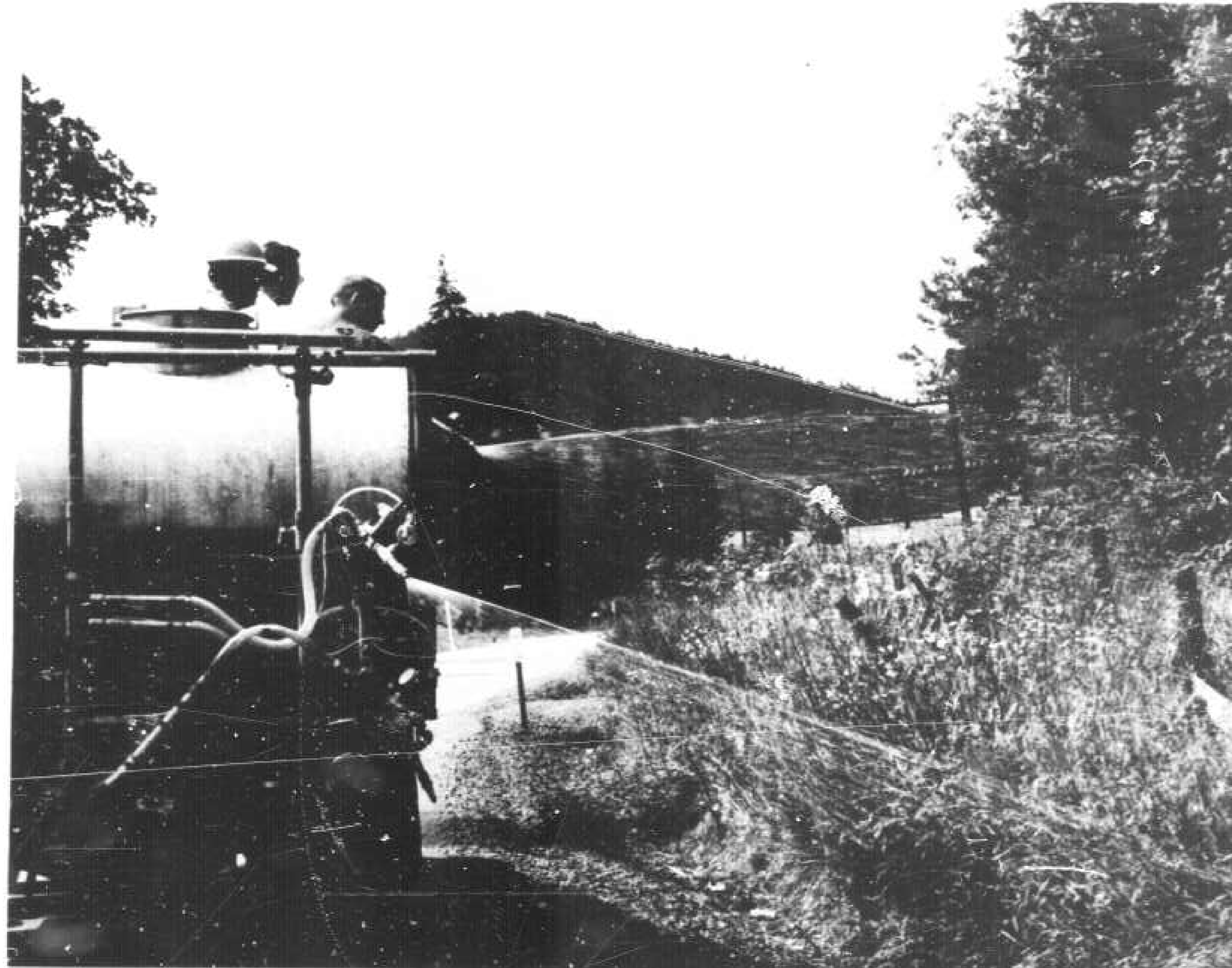
	Total Cost			Total Cost	
	Chemical	Manual & Chemical		Chemical	Manual & Chemical
1948	$ 3.13	$27.33	1957	44.55	57.73
1949	3.21	81.39	1958	16.02	26.44
1950	11.13	73.31	1959	49.21	62.00
1951	5.32	68.73	1960	50.17	66.27
1952	13.80	55.87	1961	46.19	62.39
1953	20.24	64.34	1962	38.34	52.76
1954	22.68	50.08	1963	35.89	55.42
1955	29.91	46.25	1964	47.66	63.96
1956	46.95	58.19	1965	48.00	57.53

Source: Consumers Power Company Forestry Department Brochure (1965).

The Bonneville Power Administration has about 10,000 miles of transmission lines with 56,000 acres of brush underneath. The annual cost of brush clearance with herbicides is $35 to $40/acre. Manual means would cost $300 to $500/acre (Farm Chemicals, 1967).

Roadways

In addition to maintaining the roadway and shoulders, highway maintenance forces have always been faced with the problem of vegetation control on the roadside (Figure III-B-5). For many years the task was handled solely by mechanical means. The use of herbicides on roadways came into practice about the same time that they were put to use on utility rights-of-ways. There are



Courtesy Dow Chemical Company

Figure III-B-5 - Spraying Roadway Right-of-Way about 15,000,000 acres of roadsides and highways in the U. S. Sylvester (1951) felt from the standpoint of maintenance that roadside spraying was definitely justified. Once the weeds and brush are eliminated, the prevailing grasses are given a chance to establish themselves. Many times the roadside has banks that are steeply sloped, full of rocks and debris and which one cannot gain access to with mowing equipment. Roadsides that are clean, free of weeds and brush are easy to maintain from the standpoint of snow removal.

Iurka (1960) and Zukel and Eddy (1958) have discussed the use of herbicides on highways and the following reasons have been given for their use. (1) To increase highway safety by eliminating tall weeds. Reduces driving hazards by allowing an unobstructed view of warning lights, traffic lights, crossroads, driveways and the view of curves. (2) Control broad-leaf weeds with the primary purpose of reducing the number of mowings. (3) To keep the water drainage areas free of weeds and brush which impede water flow. (4) To reduce the weed population as a source of infestation to neighboring crops. (5) To eliminate toxic plants such as poison ivy. (6) Eliminate ragweed and other allergy-producing weeds from the right-of-way.

Iurka (1960) has discussed some of the hazards concerned with herbicide applications along roadways: (1) drift; (2) volatility; (3) washoff of insoluble soil sterilants; (4) leaching of soil sterilants; and (5) public reaction to high degrees of brown-out. The utility services, such as telephone and power companies have an interest in the control of roadside brush. Unwanted vegetation which seriously interferes with power and telephone service by shorting lines has to be controlled. Many different types of herbicides are used for vegetation control along roadways (see Table III-B-3).

The rates of application of herbicides used along roadways is compared with their effectiveness on vegetation in Table III-B-4. The problem of controlling Johnson grass along Oklahoma roadways has been investigated by Sinkler et al. (1965). They reported experiments involving the use of monoborchlorate, disodium methanearsonate (DSMA) and 2,2-dichloropropionic acid (dalapon) and used the following application rates: monobor-chlorate at 640 to 1,100 lb. over 100 sq. ft., DSMA, 3 to 5 lb/acre (100 gal of water), and dalapon at 10 to 15 lb/acre. One-half of these test plots were mowed and then each treatment was applied to the regrowth when about 18 inches high. After a period of time it was determined that DSMA and dalapon treatments were more effective in reducing the Johnson grass stands whether applied to mowed or unmowed areas.

TABLE III-B-3

VARIOUS EXPERIMENTAL HERBICIDE APPLICATION RATES ALONG ROADSIDES

Chemical	Application Rates (lb/acre)	Type of Vegetation
Fenac and Amitrole		
Sodium TCA	6 + 10-50	Silver bluestem
	6 + 10-100	Silver bluestem
	6 + 16-0	Bermudagrass
	6 + 20-0	Bermudagrass
	8 + 5-100	Bermudagrass
Tritac		
Sodium TCA	4-100	Bermudagrass
	8-100	Bermudagrass
Erbon		
Sodium TCA	10-0	Bermudagrass
Hibor[a]	100-150 gal/acre	Perennial vegetation
	150-250 gal/acre	
Isooctyl Ester of 2,4-D and 2,4,5-T	6 lb. acid eq/100 gal	Sassafras, black oak, red oak, red maple sourwood
2,4,5-T acid		
2,4-D acid		
Sodium Pentachlorophenate		
Sodium TCA	20-200	Bermudagrass
Amitrole		
Sodium TCA	6-200	Silver bluestem
	8-100	Dallisgrass
Fenac		
Sodium TCA	6-200	Bindweed
	8-200	Bermudagrass

a/ Sodium metaborate 1 lb/gal.
Sodium chlorate 0.7 lb/gal.
Bromacil 0.3 lb/gal.

TABLE III-B-4

VEGETATION CONTROL BY VARIOUS HERBICIDES

Herbicide	Rate of Application[a]	Type of Application	Time Interval	Control Evaluation	Type of Vegetation	Problem Areas	Locality	Reference
Picloram Tordon 101	1 qt/acre	Hand compressor	12 months	79	Broadleaved vegetation	Highways	5 States 2 Replicates	Byrd and Nyman (1958)
	2			79				
	3		About 7 months	89				
	1			92				
	2			93				
	3			95				
Picloram Tordon 101 mixture/A	5 gal/acre	Truck spray	About 9 months	77	Broadleaved weed		4 States 8 Replicates	
	10			85				
	15			95				
	20			84				
	25			85				
Sodium Penta-chlorophenate Sodium TCA	20-100		80 Days	6[b]	Bermudagrass	Roadsides	Texas	Bowmer and McCully (1965)
	20-200			9				
	40-100			6				
	40-200			8				
	60-100			8				
	60-200			8				
Amitrole Sodium TCA	6-200	Spray boom	60 Days	7.5[c]	Silver blue-stem, dallis-grass	Roadsides	Texas	Bowmer and McCully (1965)
	8-100			5.0				
Fenac Sodium TCA	6-200			9.0	Bindweed			Bowmer and McCully (1965)
	8-200			9.0	Bermudagrass			
Fenac and Amitrole Sodium TCA	6 - 10 - 50	Spray boom	60 Days	5.0	Silver blue-stem bermuda-grass	Roadsides	Texas	Bowmer and McCully (1965)
	6 - 10 - 100			8.0				
	6 - 16 - 0			4.0				
	6 - 20 - 0			4.0				
	8 - 5 - 100			6.0				
Tritac Sodium TCA	4-100			7.0				
	8-100			6.0				
Erbon	10			5.0				
Picloram Pellets	2.9	Broadcast by hand	About 8 and 20 months	50 to 100	American elm,	Rights-of-way	Georgia Louisiana S. Carolina Tennessee	Nation (1965)
				50 to 100	winged elm, pines			
	5.8			80 to 90	Buttonbush, cypress, maple			
	8.6			100				
	60			Controlled	Buttonbush, American elm, wild cherry, wild plum, Crataegus species dogwood, elderberry, blackberry, willow, black locust, sweet gum, yellow popler, mulberry, persimmon, pines, sumac, sassafras		Georgia	Nation (1965)
	90		12 months	80 to 100	Cypress, hickory, oak			

a/ Application rate lb. per acre except where otherwise stated.
b/ 4 = treated area not distinct, 6 = treated area not easily seen but with greenish tint, 9 = all vegetation appears dead.
c/ 2 replications only.

Railroads

In many respects, effective control of vegetation on railroad rights-of-way is similar to that of roadsides. More soil sterilants come into use because the railroad ballast itself is treated. There are two general problem areas of weed control along railroad rights-of-way: (1) the track or road bed, and (2) the off-track area.

Parker (1965) and Yazell (1965) gave the following reasons for vegetation control.

In ballast section - keep good ballast draining properly.

In ballast section - enable ties and fastenings to be inspected (including switches, etc.), increasing the life of the tie.

In ballast section - keep weed seeds out of traction motors on diesel engines and prevent wheel slippage.

Shoulder adjacent to ballast - drainage.

Shoulder - unrestricted sight, enabling inspection of trains.

Around bridges, buildings and other structures - fire protection.

Yards - safety, convenience and appearance.

Noxious weeds - covered by state laws.

Around low switch stands and dwarf signals - sight.

Brush around inside of curves - inspect trains.

Brush under communication lines - uninterrupted service.

Brush adjacent to tracks - keep from fouling trains.

At highway grade crossings - sight for both autos and trains.

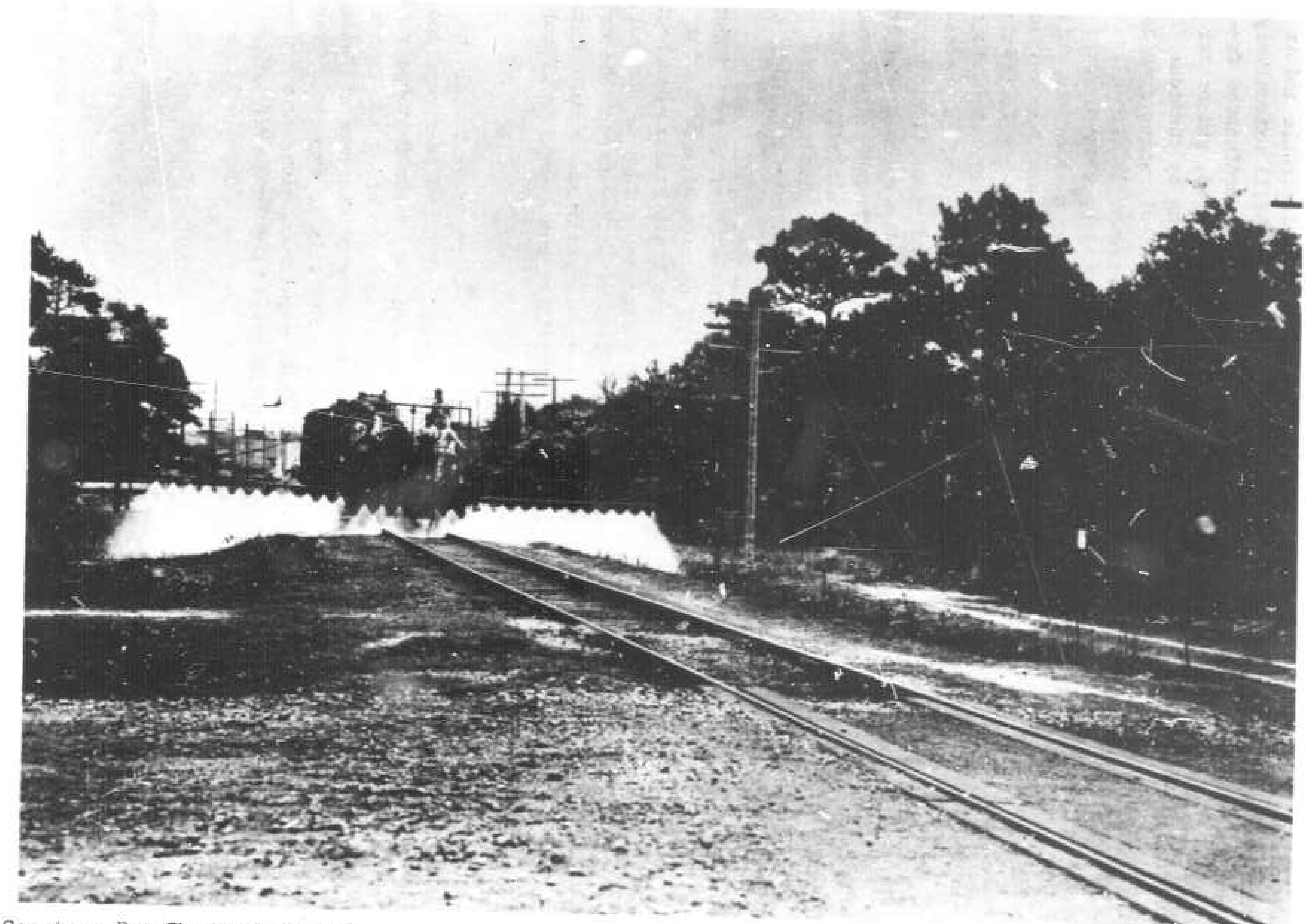
Around signs (mile posts, whistle boards) - sight.

Weed control improves the appearance of the railroad.

Historically weed and grass control methods along railroad rights-of-way parallel that of roadways and include manual removal, burning, rotary mowing and chemical control (Figures III-B-6 and -7). Burning is not selective and is almost as expensive as chemical control. Burning does not destroy the root systems

Courtesy Dow Chemical Company

Figure III-B-6 - Railroad Right-of-Way Spray Unit



Courtesy Dow Chemical Company

Figure III-B-7 - Spraying Railroad Right-of-Way in Populated Ares and creates a fire hazard. The method is now considered undesirable and is rapidly being replaced by other methods. Rotary mowing is still extensively practiced at crossings and along rights-of-way because local ordinances frequently prescribe it. However, as local ordinances are changed, and better techniques are available, many railroads are replacing mowing by chemical treatment. Along railroad rights-of-way the chemical control ranges from bare ground to selective weeding. Complete control on bare ground is expensive and requires high rates of soil sterilizing chemicals followed by reduced rates of materials with long residues. Since several railroads span most of the United States, they have special problems for vegetation control of a widely varying nature. Yazell (1965) has pointed out that continued usage of single chemicals will result in the encroachment of other types of vegetation which have to be dealt with by different herbicides. For example: (1) the use of chlorates in the southwest controls Johnson grass, but bermudagrass and vines flourish; (2) continued usage in the Midwest of contact materials plus residuals at low dosage has resulted in the encroachment of bermudagrass, bindweed, giant smart weeds, horse tail and chord grass; (3) in the areas of low rainfall, 15-20 inches, annuals are replaced by the more resistant bindweed, indian grass, buffalo grass, bluestem and Johnson grass.

Control of woody plants along railroad rights-of-way is very important, and in the past has been rather difficult and an expensive part of a maintenance program. Dormant treatment of brush with brush killers has become more popular to some areas since it does offer a high percentage of control. The application can be made in the time of the year when the susceptible crops are not growing. Brush control methods used today on railroads include dormant sprays, basal application, modified basal application, cut stump, frill and girdle tree injection.

An example of a weed control program for railroads that would be representative for the southern part of the United States has been reported by Lowry (1965) who was concerned with practices on the Cotton Belt Railroad right-of-way. They sprayed 2,4-D and 2,4,5-T with noncrop areas and ammate adjacent to crop lands in late summer and found that good coverage of foilage is absolutely necessary; usually no better than 85% kill is expected. The resistant species on their trackline are sumac, persimmon, elderberry, green ash, red maple and buttonwood. The last three years they have been using bromacils with chlorates. The latt r knock down the growth and the bromacils act as a soil sterilant.

Francisco and Aldred (1963) have discussed the program used by the Tennessee Valley Authority in controlling vegetation around their steam plants. Their steam plants have an average of 25 miles of railroad which consist of line, switchyards, transformer yards, and approximately 20 acres inside the plant (fences, riprap on intake and discharge tunnels, etc.). It is rather difficult to select chemicals for vegetation control in these areas because of two characteristics of the vegetation, deep penetrating root systems and the plants' ability to spread. Examples of herbicides and their rates of application that have been tested are as follows:

Railroads

Borate - chlorate mixture (35% active chlorate) - 6 lb/100 sq. ft.
Ammate - 300-350 lb/acre (Kudzu control)
Trysben - 8-10 lb acid equivalent per acre (Kudzu control)
Trysben - 4 gal in 100 gal of water used on sumac, conifers persimmon, sassafras, black locust and willow
2,4-D - 6 lb
2,4,5-T - 6 lb } (Trumpet Creeper)
Diesel oil - 97 gal
Sodium TCA - 100 lb/acre, or
Borate Chlorate - 6 lb/100 sq. ft. Johnson grass.

Switchyards, Transformer Yards and Fences

Telvar-W (active) - 25 lb/acre
Aminotriazole - 10 lb/acre
Simazine - 50 lb/acre
Aminotriazole - 25 lb/acre

As a result of extensive field testing by TVA, the following conclusions have been drawn:

1. Because of the many types of vegetation established, a combination of chemicals is required.

2. The wet sprays are more expensive and less effective.

3. Earlier applications would be more effective.

4. Chemical mixtures, either pellets or granular, applied by mechanical spreaders would be more effective and economical.

Their experience indicates that after the first year's treatment, only spot treatment is needed in the second year. Two years later, again only a spot treatment is required. They found that the most troublesome vegetation to reoccur was trumpet creeper, honeysuckle, briars and crabgrass. The best combination for spot treatment was a mixture containing 80% disodium tetraborate pentahydrate, 13% disodium tetraborate decahydrate (boron trioxide equivalent 43%), 3% 3(p-chlorophenyl)-1,1-dimethylurea (monuron) and 1% trichlorobenzoic acid (TBA).

Pipelines

The first pipeline constructed to transport oil under pressure was laid down in 1865 (Bell, 1965). This line was 5 miles long, having a 2-inch diameter pipe and was able to move about 800 barrels of crude oil a day. The pipeline is a great saver of money in the transport of crude and petrochemicals. A gallon of oil can be moved from the East Texas oil fields to Toledo, Ohio, for less than a penny. There are more than three million acres of pipeline rights-of-way in the United States (Bell, 1965) and less than 30,000 (1%) receive any form of chemical treatment. One of the reasons for the small amount of brush control on pipeline rights-of-way has been the history of poor public relations between companies and land owners (Bell, 1965). In 1940, the Justice Department brought suit against virtually all the pipeline companies in the United States, charging excessively high tariff, which resulted in refunds and rebates to shipper-owners under the guise of earnings or dividends. This was supposedly in violation of the Elkins Act. Later, the pipeline companies and the Justice Department entered into a consent decree in 1941, which many people regarded as admission of guilt on the part of the pipeline companies. Improved technology, expanding petroleum demands, and in general, the realization of their public relations image caused some companies to alter their negative public relations attitude.

The petroleum industry has a need for vegetation control for (1) removal of fire hazards, (2) aerial surveillance of pipeline for detection of breaks, (3) control of noxious weeds, and (4) establishments of good public relations.

Vegetation control is needed aro[illegible] e types of areas connected with the recovery and transport of crude oil

1. Christmas tree-valves and piping at the well site

2. Tank battery - this is a group of storage tanks that the crude oil flows into from the well head or Christmas tree

3. Related facilities

   a. heaters

   b. valve manifolds

      (1) compressors

      (2) field offices

      (3) gas plants

The sequence of a management program for the control of vegetation in these areas would inclu` : (1) a survey to determine soil types, vegetation density and type, (2) ormulation of a program to use the proper types of herbicides, (3) use trained personnel for application, and (4) keep adequate records so that one can evaluate the cost of controlling the weeds.

Prior to World War II, vegetation was controlled mechanically, using crews of men with hoes and rakes and cutting devices to remove the weeds on all company property. Other methods were tried such as the use of oil and salt water. Crude oil was not satisfactory because the concentrations required to sterilize soil conditions constituted a fire hazard. The use of salt water, although a fair herbicide, involved cost of application and transportation which was prohibitive. Hubbard (1965) has the following to say about the Humble Oil Company spray program. An example of the size of the areas to be treated around the various facilities is as follows:

1. Christmas trees - 30 ft x 30 ft.

2. Piping manifolds and remote heaters - 100 sq ft.

3. Field headquarters, compressors and gas plants - 1/2 to 5 acres.

The wells, based on 40-acre spacings, distance between fields, 50 miles, amounts to about 93 acres of small plots within the boundaries of an area encompassing 12,600 sq miles. As a result of the Humble Oil Company's experience with soil sterilants (Hubbard, 1965) they have settled on an initial treatment consisting of 30 lb/acre of diuron or monuron, mixed with a surfactant and 400 gal of water per acre. They followed this application with spot retreatment in July, which consists of 30 lb/acre of bromacil with surfactant and TCA mixed in 400 gal of water. Some of the cost evaluations are as follows:

1. Prior to World War II, hand control of weeds, depending upon location, costs from $300 to $800/acre.

2. The use of soil sterilants runs from about $100 to $275/acre.

3. The cost of application of monuron or diuron in the above described procedure, including factors which influence the treatment costs is type of soil, type of density in growth and density in number of facilities treated. The total treatment costs varied from $51.38 to $192/acre with labor costing $25.96 to $88/acre and material from $25.42 to $148.29/acre.

Firebreaks

Firebreaks are convenient methods to limit fire spread in forests and on rangeland. This is usually done by cultivating a soil barrier around a designated area. In the Nebraska sand hills, the Bessey National Forest utilizes disked strips. There are some inherent disadvantages in this technique in that it exposes the sandy soil to wind and water erosion. An excellent paper has been reported by Bovey and McCarty (1965) describing the testing of 31 soil sterilant herbicides. A list of the herbicides used in this treatment with the application rates are shown in Table III-B-5. The herbicides were sprayed with a hand boom sprayer on square rod plots in triplicate. One series was used on undisked land and another series on disked land. The predominant grasses in the experimental areas were prairie sand reed, sand drop seed, little bluestem, hairygramma; the broad-leaved species were lead plant, poison ivy, wild rose, and sunflower. In these tests, all effective herbicides applied as foliar sprays lost their effectiveness after the first year (Table III-B-6). On the disked areas, however, simazine at 40 lb/acre, diuron at 7.5, 15, and 40 lb/acre and BMM* at 1,300 lb/acre remained effective for at least two years. Diuron gave the most effective vegetation control of all the chemicals tested.

TABLE III-B-5

VARIOUS EXPERIMENTAL HERBICIDE APPLICATION RATES ALONG FIREBREAKS TO CONTROL GRASSES AND BROAD-LEAF WEEDS

Chemical	Application Rates (lb/acre)
Erbon	60, 80, 100
Atrazine	7.5, 15, 40
Dalapon + (Atrazine-simazine)	3.75 + 7.5
	5 + 20
	5 + 40
Paraquat + (Atrazine-simazine)	1 + 10
	1 + 20
	1 + 40
Amitrole + simazine	2.5 + 7.5
	5 + 15
	10 + 30
Simazine	3.75 - 40
Atrazine	3.75 - 40
Diuron	3.75 - 40
BMM*	162.5 - 1,300

Disodium tetraborate 93.1%, monuron 3% and TBA 1%.

TABLE III-B-6

CONTROL OF VEGETATION[a] ON FIREBREAKS UTILIZING VARIOUS HERBICIDES SINGULARLY AND IN COMBINATION

Herbicide	Application Rates (lb/acre)	Control Evaluation[b] Seasons 1962	1963
Undisked			
Erbon	60	90%[c]	40%
	80	90	7
	100	100	5
Atrazine	7.5	25	5
	15.0	40	20
	40.0	80	5
Dalapon	3.75 + 7.5	85	15
	5 + 20	90	20
	5 + 40	100	60
Disked			
Paraquat	1 + 10	70	20
	1 + 20	65	20
	1 + 40	95	20
Amitrole + simazine	2.75 + 7.5	5	0
	5 + 15	70	20
	10 + 30	60	20
Simazine	3.75	80	65
	7.5	75	40
	15.0	85	70
	40.0	95	100
Diuron	3.75	80	55
	7.5	100	100
	15.0	90	95
	40.0	95	100
BMM	162.5	95[c]	80
	325.0	100	80
	650.0	100	90
	1300.0	80	100

a/ Vegetation--grasses and broad-leaf.
b/ Time from treatment to evaluation--1 and 2 years.
c/ Average percentage of three replicates.

Source: Bovey, R. W., and H. K. McCarty, Establishment of firebreaks in forest and rangeland with herbicides. J. Range Mgmt. 18 (5), 282-283 (1965).

Some Aspects of the Ecology of Rights-of-Way

The rights-of-way for power, communication, roadways, and pipelines are unusual noncropland areas in that they are a continuous network extending for thousands of miles over the United States. The rights-of-way pass through all of the environments represented by a broad spectrum of climatic and edaphic systems. The vegetation along the rights-of-way is as diverse as all the vegetation patterns represented in the country. Obviously, rights-of-way traverse many types of ecosystems. Furthermore, the rights-of-way for power, communication (nonroadside lines), and pipelines may exist relatively undisturbed by man for long periods of time. In contrast, roads and railroads represent entirely different ecological systems which are continuously disturbed by population pressure, noise and pollution.

The greatest change that takes place in rights-of-way from an ecological viewpoint is the initial disturbance of the vegetation. The disturbance of the fauna and lower forms of organisms is secondary. In rights-of-way, we have a complex of interactions between trees, shrubs, herbs, animal life, arthropods, mollusks, fungi and other organisms. The ecological relationships among these biota and the abiotic factors of the environment represent an ecosystem.

Power, communication and pipeline rights-of-way are usually cleared initially by mechanical means, whereas thereafter they are maintained largely by herbicidal treatment, combined in some instances with mechanical methods. The maintenance of rights-of-way is necessary along power and communication lines in order to keep the area close to the wires free of vegetation. If the foliage is allowed to return to its original state, access would be denied to maintenance crews and there would be a risk of "shorting" occurring between high-voltage transmission lines and the vegetation. Niering (1961) has suggested one form of management of right-of-way vegetation that is based on sound ecological principles.

1. Central part of right-of-way, directly under the wires. All tall-growing trees which might eventually grow or fall into the lines are removed. Low-growing shrubs and scattered taller shrubs are preserved. In general, shrubs that eventually grow over 3 ft in height should be removed if they occur in large colonies which spread over the ground for distances of 25 ft or more. A trail 8 to 10 ft in width, preferably composed of grasses, should be maintained in order to permit access for inspection and repair. A similar pattern is recommended around the bases of poles and towers.

2. The sides of the right-of-way, between the outermost wires and the forest edge. Tall-growing trees which might eventually grow or fall into the lines are removed. Therefore, along the sides all shrubs and low-growing trees are preserved to form the densest possible cover so as to resist future invasion by trees.

3. Forest edge adjacent to the right-of-way. Here tall-growing trees are removed before they reach the height of the wires. This eliminates the danger of trees falling into the wires and avoids costly cutting operations in the future.

There are a number of interests involved in maintenance of rights-of-way, the utility company, the land owner who has granted the easement, the county and state highway commission and the general public who have a high exposure to the roadways and railways. There is probably no form of vegetation management that is as obvious to the general public as that exercised along our vehicular rights-of-way. The conservation minded public and the land owner, and in some sense the general public are interested in these areas from the standpoint of the values that could be derived from the areas, if properly managed (Niering, 1958).

1. General conservation values. These values are recognized by all conservation-minded groups. They are important for the greatest social good - now and in the future.

2. Wildlife habitat. The concern of biologists in general, involving various clubs and societies. Here, wildlife includes song birds.

3. Game habitat. This is the chief interest of the various State Game Departments as well as sportsmen and sportsmen's clubs. The values of the rights-of-way are for the production of and to increase game populations and not as shooting areas.

4. Forestry values. The concern of foresters, primarily in obtaining suitable stands adjacent to the rights-of-way and removing threats of disease or insects to timber species.

5. Habitat for flowering herbs and rare plants. Of particular interest to State Botanical Societies and to professional and amateur naturalists and botanists. The preservation of species or associations that might otherwise become extinct is of primary importance.

6. Landscape and aesthetic values. The concern of Garden Clubs and the general public, especially where lines cross or are seen from public roads.

There have been three relatively long-term controlled vegetation and ecological studies carried out on definitive areas of vegetation; Aton forests (400 acres) in Northwestern Connecticut initiated in 1946 (Egler, 1947, 1948, 1950, 1953); the Connecticut Arboretum right-of-way demonstration initiated in 1953 (Niering, 1957, 1960); a 3 mile section of the Pennsylvania Electric

Company's power line in Centre County, Pennsylvania, started in 1953 (Bramble and Byrnes, 1955a, 1955b, 1956, 1957, 1958, 1966, 1967). The objective of Egler and Niering's work was to develop a vegetation control management system that would lead to a stabilized plant community. The approach was to selectively spray to promote the growth of a varied mixture of grasses, forbs and shrubs. The development of shrublands was considered by Egler to be closed communities not being invaded by tree seedlings. He felt that the summer foliage blanket spraying was not successful in controlling the growth from root suckering species such as black locust, ailanthius, quaking aspen and sassafras.

Egler (1953) outlined some principles of vegetation management. He indicated that rights-of-way were nothing more than nonforested land which tend to develop into forests. All new disturbed areas tend to progress more or less quickly to some forest type. The normal course of development from open land to forests passes through the following stages: (1) annual weeds, (2) grasslands, (3) shrublands, and (4) forests. He dealt with two interpretations of physiognomic development, namely relay floristics and initial floristics composition. The theory of the former assumes that the invasion of new species is in turn killed out by the species of the previous stages. He spoke of initial floristic composition as a hypothesis assuming that the sequential invaders, weeds, grasses, forbs, shrubs and trees are all present on or in the soil at the beginning following an over-grazing, a fire, or other types of destruction, existing in the form of seeds, seedlings, or shoot producing roots.

Gratkowski (1967) has pointed out that in brush field reclamation the ability of plant species to germinate, survive, grow and reproduce in a habitat depends upon their efficiency to compete for light, soil moisture and nutrients. Competition for light is the function of the above ground portions of the plant, whereas the competition for soil moisture and mineral nutrients are confined to the root systems. Gratkowski notes that the number of research efforts for the study of root systems has been limited and that much of the information is contradictory. The competition for nutrients by root systems is not as severe as competition for soil moisture. Gratkowski cited a paper by Tew (1966) who studied the depletion of soil moisture by Gambel oak in northern Utah. He estimated that Gambel oak extracted 11 to 13 inches of moisture from the upper 8 ft of the soil during the growing season.

Niering (1961) reported on the techniques used at the Connecticut Arboretum for managing a utility right-of-way plot 1,500 ft long. They utilized both knapsack sprayers as well as commercial power equipment. Basal treatment gave effective root kill in all seasons,but the root collar applications weremore effective. White oak showed some resistance to root kill. Stem foliar treatments were not too successful against sassafras and aspen and they frequently resurged profusely after spraying. Late or mid-summer basal or root collar treatments were effective on aspen as well as sumac. Niering was interested in preserving low shrubs, such as huckleberry, low bush blueberry, sweet fern and others which have a tendency to form a tight ground cover and prevent the invasion of tree seedlings. Also the shrubs and low trees that are left provide excellent food and cover for wildlife.

Currently, spraying of power and communication rights-of-way is accomplished by the use of helicopters, fixed wing aircraft and mobile units along the roads. It is common practice in the southern deciduous-pine forests to spray the rights-of-way every three to five years. The spraying is controlled to reduce the height of the vegetation and much of the right-of-way does not revert to a grassland stage. The advent of aerial application has solved the difficult logistics of transporting herbicides by carriers for long distances into inaccessible areas. In recent times, there are two problems involving the cost of right-of-way maintenance that have become more paramount than all other factors, and that is cost of and the lack of sources of qualified manual labor.

For example, agricultural practice in recent times has been characterized by the elimination of the smaller farms in order that the utilization of modern high priced farm equipment might be more efficient. The farm hand, the "hired hand" of the 1920 era and before has almost totally disappeared from the scene.

There is a question whether the selective basal or root collar technique is feasible from an economic standpoint. This approach to vegetation management appears to have been successful at least over the period of time that reports are available. It would be valuable for its complete appraisal if cost data were available.

Some comments of Hampson (1966) concerning the use of knapsack mistblowers on the National Lead Company main power transmission line rights-of-way in northern New York is of interest here. They have evaluated the method for two years in a preliminary study and have five years of field test experience. Hampson felt that the selection of an optimum approach to brush control for given set of circumstances involves the skillful blending of two factors: treatment cost and long-term effectiveness. A very expensive treatment, such as cutting and stump spraying may be justified if it provides adequate control for sufficient long period of time.

They used a low volatile ester of 2,4,5-T, containing 4 lb. of acid per gallon. They sprayed the 100-ft right-of-way, utilizing three operators working abreast. Daily ground coverage of three operators ranged from 10 to 25 acres. The cost breakdown for herbicides, labor, supervision, vehicles, mistblower expense for a 200 acre plot, was $27.78/acre.

Problems concerning mistblower operation: (1) application of 2,4,5-T left softwood stems largely unscathed, (2) limiting problem in small areas with tall brush, up to 30 or more feet in height, they resorted to using ultra-light direct drive chain saws, (3) 20% of the cost of brush control was distributing the bush chemical along the rights-of-way.

Bramble's studies summarized in 1967 were concerned with the ecological aspects of brush control. His objectives were (1) to determine the effectiveness of chemical brush control on game food, and cover, (2) to study the game usage of the treatment areas, and (3) to follow the effectiveness of the original treatment of brush control with and without subsequent sprays. This series of studies, reported over a period of years from 1953 to 1967, represent the best in depth examination of the relation of spraying to the ecological aspects of the sprayed areas. He employed six brush control treatments in four replications. One year following the initial spray, a follow-up basal spray was applied to one-half of each treatment area of five original treatments. Treatments and follow-up sprays were as follows:

A. Unsprayed, cut as needed for control.

B. Broadcast foliage spray of 2,4-D plus 2,4,5-T butoxyethanol esters, half and half; at a concentration of 4 lb. aehg (acid equivalent per 100 gal) in water. Applied June 1953.

C. Oil-water, semi-basal spray of emulsifiable acids of 2,4-D plus 2,4,5-T, half and half; 3 gal of spray material to make a concentration of 6 lb. aegh in an oil-water carrier consisting of 10 gal of No. 2 fuel oil in 87 gal of water. Applied June 1953.

D. General summer basal spray of emulsifiable acids of 2,4-D plus 2,4,5-T, half and half, at a concentration of 12 lb. aehg in No. 2 fuel oil. Applied June 1953.

E. Selective winter basal spray of 2,4,5-T butoxyethanol esters at a concentration of 12 lb. aehg in No. 2 fuel oil. Applied February 1954.

F. Broadcast foliage spray of ammate at a concentration of 3/4 lb/gal of water; 4 oz of DuPont sticker-spreader were added per 100 gal of spray. Applied June 1953.

B-D, C-D, D-D, E-D, F-D - A follow-up basal spray (D) applied in June, 1954 (June 1956, for E-D) to one-half of each replication of treatments B, C, D, E, and F. The follow-up consisted of a summer basal spray using ACP formula 1054-E containing 2 lb. of 2,4-D and 2 lb. of 2,4,5-T per gallon, used at the rate of 16 lb. aehg in fuel oil.

In regard to the control of woody plants of all the spray treatments listed above, the semi-basal spray was superior to the other treatment (Table III-B-7).

TABLE III-B-7

TOTAL NUMBER OF WOODY PLANTS PER ACRE IN THE SHRUB LAYER, OVER 3 FT IN HEIGHT, IN JUNE 1965, 13 YEARS AFTER ORIGINAL TREATMENT

Treatment	Bear Oak	Other Oaks	Red Maple	Sassafras	Witch-hazel	Cherry	Misc. Hardwoods	Total	Total Minus Sassafras
Single Initial Spray									
A Unsprayed	152	374	154	74	184	4	14	956	882
B Broadcast D + T	90	6	0	2	12	0	0	110	108
C Semi-basal	38	4	0	0	18	0	0	60	60
D Summer Basal	68	44	32	334	64	10	4	556	222
E Winter Basal	143	124	30	748	87	4	0	1136	388
F Broadcast Ammate	14	20	112	8	78	10	0	242	234
Initial Spray with Follow-up Basal									
B-D Broadcast D + T	14	2	0	4	8	0	0	28	24
C-D Semi-basal	12	8	10	0	18	40	4	92	92
D-D Summer Basal	20	32	20	4	110	96	4	286	282
E-D Winter Basal	57	20	0	16	3	0	0	96	80
F-D Broadcast Ammate	6	4	2	2	56	0	0	70	68

Source: W. C. Bramble and W. R. Byrnes (1967).

The summer and the winter basals were the poorest due to the lack of effectiveness of controlling sassafras. A combination of an initial spray plus a follow-up basal spray was more effective than the initial spray. The best control was obtained in the 2,4-D + 2,4,5-T plus basal spray plots. The semi-basal and winter basal with a follow-up basal spray were only slightly poorer than the other treatments.

One of the objectives of the experiment was to develop a stable ground cover. The selective basal sprays were highly successful in maintaining the original Bracken-Hedge-Herb-Blueberry plant community. The broadcast spray areas returned to essentially the original plant components in five years.

Bramble and Byrnes (1955, 1956, 1958, 1967) studies of the trends in animal populations in the various test plots is highly important from an ecological viewpoint. Their observations are summarized as follows:

Deer - Observed in all areas and the total usage of these areas was increased.

Grouse - Observed in all areas.

Turkeys - Used treatment areas, broadcast foliage spray areas, flocks were observed in the summer when they fed upon insects.

Squirrels - Use of rights-of-way was along the edge where most producing trees were concentrated.

Rabbits - Increased in the treatment areas.

All the major species of plants composing the dominant plant cover were used by the major game species found in the area (Table III-B-8).

Gysel (1962) began a study of vegetation changes and animal use of rights-of-way in 1957. Some of his observations after five years are as follows:

1. Most marked changes in plant density and species composition occurred where foliage spray was used.

2. Only minor changes occurred in plant communities where basal treatment was used.

3. A variety of trees, bushes, and herbs occurred in both sprayed and unsprayed areas.

4. Many kinds of fruits and much browse was available to wildlife species.

5. Sixteen species of mammals and 19 species of birds were trapped or observed in the rights-of-way.

6. Rabbits, deer, grouse, and pheasants utilized the rights-of-way (treated and untreated areas) during the winter.

TABLE III-B-8

UTILIZATION BY GAME OF COMMON PLANT SPECIES THAT OCCUR ON THE RIGHT-OF-WAY AS OBSERVED AND RECORDED

	Deer				Grouse				Turkey				Rabbit			
Herbs and Grasses	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W
Bracken	H	H	-	-	-	-	H	-	-	-	-	-	-	-	-	-
Sedge	H	L	L	H	-	-	L	L	L	H	L	L	-	-	-	-
Loosestrife	H	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panic Grass	L	L	L	L	-	-	L	-	-	H	H	H	H	H	H	H
Goldenrod	L	L	-	-	-	L	-	-	-	-	-	-	-	H	H	-
Fireweed	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shrubs																
Blueberry	H	L	L	H	-	H	H	H	-	H	-	L	L	L	L	H
Teaberry	L	L	L	L	H	H	H	H	-	L	L	L	-	-	-	-
Blackberry	L	L	L	L	L	H	H	H	-	H	L	L	H	H	H	H
Sweetfern	H	-	H	H	-	-	L	L	-	-	-	-	-	-	-	L
Witchhazel	L	L	L	H	-	-	H	H	-	-	H	L	-	-	-	L

H = Eaten commonly or heavily utilized.
L = Eaten rarely or sparsely utilized.
Season - Sp, spring; Su, summer; F, fall; W, winter.

Source: Bramble, W. C. and W. R. Byrnes (1967).

C. Herbicides in Forestry

Nearly one-third of the land area of the coterminous United States--638 million acres altogether--is wooded. Much of this forest is not managed, since it is found on rough, poor land, often in mountainous areas. Of the 502 million acres of "commercial forest," a substantial 30% is forested farmland. The geographic distribution of forest areas by types is shown in Figure III-C-1.

Herbicide applications in forestry have been most intensively developed and practiced on the 66.7 million acres maintained by commercial forest industries, and on the 91.5 million acres of National Forest Land (Table III-C-1).

TABLE III-C-1

OWNERSHIP AND USE OF FOREST LAND
IN THE 48 UNITED STATES
(Thousands of Acres)

	Acreage	% of Commercial Forest
Commercial Forest Land a/		
Federal	107,582	21.4
National Forest	(91,500) b/	(18.2)
Other Federal	(16,082)	(3.2)
State, County and Municipal	28,058	5.6
Private	366,354	73.0
Forest Industries	(66,628)	(7.0)
Pulp and Paper	(35,022)	(5.2)
Lumber	(26,113)	(1.1)
Other	(5,493)	
Farm	(150,651)	(30.0)
Other Private	(149,075)	(29.7)
Total Commercial Forest Land	501,994	100.0
Noncommercial Forest Land	136,401	
Total Forest Land	638,395	

a/ Commercial Forest Land includes all land which was producing or was physically capable of producing usable crops of wood as of January 1, 1963.

b/ Figures in parentheses represent breakdown by ownership of the major forest classes.

Source: Statistical Abstract of the United States, 1967, p. 658. U. S. Dept. of Commerce, Bureau of the Census.

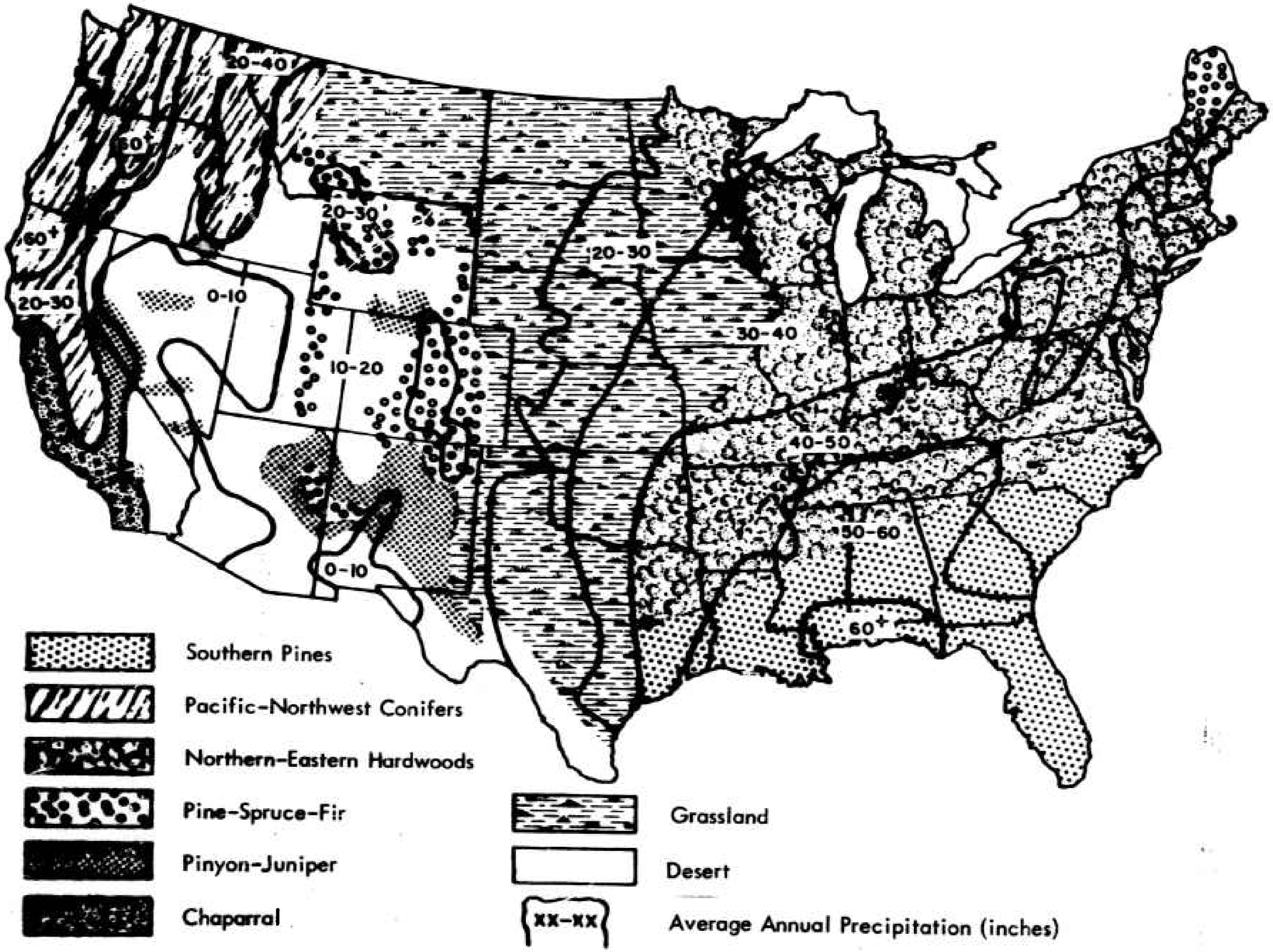


Figure III-C-1 - Distribution of Forest Types in the United States

Historical Background

Although chemicals are not new to the field of forest management, relatively little use of herbicides was made prior to 1945. An important reason why herbicides were not widely used had to do with the limitations of the chemicals that were then available. The history of herbicides in forestry has been reviewed by McQuilken (1960). Sodium arsenite was used to kill woody plants, and ammonium sulfamate was used for nonselective weed control. There was a recognized need for better silvicides, and for selective weed-control chemicals.

As early as 1945, information was being acquired on the effects of 2,4-D on forest plants. Stahler (1945) reported that white and jack pines, white and black spruces, red cedar, and some dogwoods were uninjured by 1,000 ppm of 2,4-D. He also found that seedlings of American elm, hard and soft maples, cottonwood, and alder were quickly killed by similar concentration in mid-May, but reacted more slowly to summer and fall applications.

Data from early University of Minnesota studies are summarized by Buchholz (1946), together with other regional information comparing results using various 2,4-D salts, amines, and ester formulations on 18 woody plants, including species of *Pinus* and *Juniperus*. This summary also rated the plants under "killed, resistant, and variable." Annual summaries were prepared by Melander (1947, 1948, 1949, 1950), Hansen (1951, 1952, 1953, 1954, 1955, 1956), Kuntz and Holm (1960, 1961), and Beatty (1960), giving the results of regional research on woody plants.

While considerable management use of herbicides as well as the early research on phytocides involved ground applications by back-pack sprayers and powered equipment, large-scale forestry application may be considered to have started with the development of aerially applied treatments.

In 1949 and 1950, the first reported (Offord et al., 1950) use of helicopters for applying phytocides to forests described the application of 2,4-D and 2,4,5-T for purposes of eradicating *Ribes*, for suppressing brush in forest plantations, and for a desiccant preliminary to burning in the forest. In 1951, two tests were made in Minnesota of the use of aerial applications for silvicultural purposes. One tested the effectiveness of 2,4-D for low-land brush control (Roe, 1952) and the other tested for release of jack pine from heavy oak competition.

Chemical debarking prior to harvest, using sodium arsenite, was introduced in Canada in 1942. Considerations of toxicity, corrosion and losses due to bark beetles have led forest managers to look for better chemical agents.

Current Uses of Herbicides

Since 1945, continuous advances in chemical formulations and application methods, as well as extension of knowledge about specific action of various herbicides and the accumulation of years of practical experience, have helped to make herbicides a standard tool for forest management.

Today, herbicides are employed at every stage of silviculture, from land conversion and nursery planting to the harvesting of mature timber stands.

Forest management* and silviculture primarily involves measures designed to control competition among forest species and to provide favorable growing conditions for the preferred species. Herbicides, such as the chlorophenoxy compounds, amitrole, atrazine, picloram, cacodylic acid and fenuron, enable foresters to provide the kind and degree of control needed in various stages of forest cultivation. Some of the more important areas of herbicide use will be described briefly.

Forest Nurseries

Forest-tree nurseries present weed-control situations which differ from most other types of plant culture. The usual system of growing seedlings of a single species at relatively high density in thousands upon thousands of linear feet of 4-ft wide beds is perhaps unmatched in magnitude and intensity among other plant-propagation practices.

Weed control is one of the major nursery production costs, but can be justified in terms of the high cash value of the crop involved. Hand-weeding is still necessary in all nurseries. Chemical herbicides, where applicable, may reduce weeding costs by more than 50%.

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* The Society of American Foresters (1958) defines forest management as "The application of business methods and technical forestry principles to the operation of a forest property." Davis (1965) indicates the range of technological and business tasks involved:

Technological Aspects		Business and Social Aspects	
Silvics & silviculture	Fire control & use	Economics	Marketing
Mensuration	Wildlife	Organization & administration	Business law
Logging & milling	Recreation		Labor relations
Wood technology	Grazing	Finance	Real estate
Pathology	Water	Accounting	Social & political science
Entomology	Civil engineering	Statistics	

The weed-control chemical used most widely in forest nurseries has been mineral spirits. Applied undiluted, at rates of 25 to 50 gal/acre of seed beds, these solvents provide selective weed control for pines, spruces, and firs. Because a few conifers, notably the larches, cannot tolerate oily sprays, safer herbicides are being sought.

Planting-Site Preparation (Conversion)

Land which needs planting to restore it to timber production is normally covered with brush or small trees of inferior quality. Brushfields and cut-over areas must be converted for successful planting and reforestation. Often such clearance is accomplished by mechanical means, or by prescribed burning. Herbicides are now used to an increasing extent in site preparation for forest planting.

Site preparation generally includes: (1) removal of brush or herbaceous cover; (2) grading or removal of physical obstacles; and (3) scarification of the ground surface to provide a more favorable seedbed for direct and natural seeding. The most effective and widely used herbicides are low-volatile esters of 2,4-D and 2,4,5-T. Other chemicals used on special sites include silvex, amitrole and amitrole-T. Aerial application of atrazine at 2 to 4 lb/acre to control grasses and herbaceous vegetation has been a noteworthy recent development.

Bentley (1967) has described brushfield reclamation within the commercial timber zone of California. During the period, 1962-1965, careful studies of herbicides on the Sierra Nevada and Cascade Ranges have served to promote confidence in herbicides and to prepare guidelines for their use on accessible land. Brush is cleared by various combinations of bulldozing and burning. Timber sites on steep or rocky land can be sprayed with herbicide to prepare the brush fuel; followed by prescribed burning.

The control of brush regrowth is essential regardless of the method used for clearance. Broadcast spraying or aerial spraying with herbicides over several years is required to suppress brush with minimum damage to pine seedlings. Application of 2,4,5-T at 4 lb. (acid equivalent) per acre in August or September causes little or no damage to pine seedlings. But where swaths overlap and the rate is doubled, some damage to seedlings has been observed. In some trials, however, no damage has been found when 8 lb/acre was applied without overlap.

In the eastern United States, a common brushland cover is the scrub oak type, of which Pennsylvania has upwards of 200,000 acres. McQuilkin (1960) has reviewed herbicide history and uses at all stages of silviculture for this region.

The South has different problems. In Florida, the brush problems with titi (Cyrilla racemiflora), turkey oak (Quercus laevis), and wiregrass (Aristida stricta) have been described by Beers (1961). In swamp conversion where heavy equipment is impractical, there is no mechanical alternative to the use of herbicides.

Low quality hardwood sites can be prepared by applying pelleted herbicides to the soil. Shipman and Eichert (1967) summarized results obtained with four chemicals: fenuron, picloram, dicamba and fenuron with TCA (Table III-C-2). Forestry studies with solid forms of herbicides have been actively pursued by a number of investigators, including: Herron and Newman (1961), Shipman (1963a & b), Sowers (1964), Eichert (1965), and Shipman (1966a & b).

Release of Desired Species

Herbicides are the standard tool for minimizing competition from undesirable plants, and promoting growth of the desired species. The most common forest application of herbicides is release of conifers from deciduous hardwoods in mixed stands.

Although hardwoods may be treated by hand or power spray from the ground, the development which has made release economical is large scale aerial spraying of 2,4,5-T. The selectivity of 2,4,5-T acts upon hardwoods with little injury to conifers. One of the first published reports of aerial release was by Hawkes (1953) in the Pacific Northwest. About this same time, Arend et al.(1953)conducted tests at the Lake States Station; the next year, the first aerial release in the Northeast was performed by McConkey (1954).

Undesirable hardwoods are encroaching on "pine land" in the Southeast at a rate of 600,000 acres/year. To control such weed trees, the low volatile esters of 2,4,5-T and 2,4-D are used almost exclusively. Rates of application range from 2 to 6 lb (acid equivalent) per acre. Arend (1960) has reviewed the factors associated with application both from fixed-wing aircraft and from helicopter. The choices of carrier, spray volume and seasonal timing of application are all important in the degree of top kill obtained. Some workers report improved results from the use of invert emulsions (Darrow, 1959).

Table III-C-2

TOPKILL AND SURVIVAL OF UNDERPLANTED PINE SEEDLINGS IN RELATION TO CHEMICAL TREATMENT BY LOCATION
(in percent)

Treatment		Location							
		Area 1 Black Moshannon a/		Area 2 Stone Valley b/		Area 3 The Barrens c/		Mean (all locations)	
Chemical	Rate	Topkill	Survival	Topkill	Survival	Topkill	Survival	Topkill	Survival
Fenuron	20 lb/acre	62	84	67	85	82	80	70	82
	40 lb/acre	67	66	92	67	96	71	85	68
	1 tsp/1 in. dbh			95	88	94	92	94	90
	1 tsp/2 in. dbh			81	86	92	91	86	88
Picloram	20 lb/acre	36	85	45	84	19	85	34	84
	40 lb/acre	68	70	76	73	5	89	50	76
	1 tsp/1 in. dbh			62	88	34	87	48	87
	1 tsp/2 in. dbh			38	87	9	92	23	89
Fenuron with TCA	20 lb/acre					48	94	48	94
	40 lb/acre					91	89	91	89
	1 tsp/1 in. dbh					83	87	83	87
	1 tsp/2 in. dbh					61	97	61	97
Dicamba	20 lb/acre					6	93	6	93
	40 lb/acre					17	88	17	88
	1 tsp/1 in. dbh					16	95	16	95
	1 tsp/2 in. dbh					13	94	13	94
	Control	0	96	0	97	0	95	0	96

a/ No significant difference between topkill means (unburned only); $LSD_{0.05}$ between survival means = 4.5[illegible]%: includes all stems 1 inch in diameter at breast height and larger.

b/ $LSD_{0.05}$ between topkill means = 1[illegible].34%; $LSD_{0.05}$ for survival = 10.21%.

c/ $LSD_{0.05}$ between topkill means = 15.60%: survival means = 12.31%.

Source: Shipman and Eickert, Journal of Forestry (1967)

According to Theisen (1967), about 99% of release treatment in the Pacific Northwest is done by aerial application of herbicides from helicopters. The remaining 1% is sprayed with back-pack mistblowers, or by direct application of herbicide to axe frills cut in the trunk. In the last 12 years, about 34,000 acres of the Siskiyou National Forest have been treated.

Even though low volatility formulations (iso-octyl ester, 2,4,5-T) are used, special precautions are observed to guard against possible damage due to spray drift. Aerial spraying is not permitted whenever any of the following conditions occur:

(1) Wind exceeds 6 miles/hr,

(2) Temperature exceeds 75°F,

(3) Snow or ice covers brush,

(4) Rain is falling,

(5) Foggy weather occurs,

(6) Relative humidity is below 50%, or

(7) Air turbulence is sufficient to affect the normal spray pattern.

Timber-Stand Improvement

Elimination of cull trees in low quality pole- and saw-timber stands is generally called timber-stand improvement (TSI); in commercial forest plantations, such selective tree killing is termed "thinning." By whatever name, undoubtedly more chemicals have been used over a longer period in this kind of forestry work than in any other. Tree girdling was used in the days of CCC work; today modern silvicides are used to do the job faster, more reliably, and at lower cost.

Although aerial spraying is used where nearly complete suppression of hardwoods is needed in pine, spruce or fir stands, for the most part, the man on the ground applying individual treatment to cull trees is indispensible.

With financial support from the Agricultural Stabilization and Conservation Service, and the Farmers Home Administration, many of the marginal stands of pole-size timber have been culled, cut and thinned. Usually the trees are cut and the stumps sprayed with 2,4,5-T in fuel oil to prevent sprouting. Alternatively, brush killer can be applied in frills cut into the bark, and trees left standing.

Commercial Chemi-Thinning

A plantation established at the older conventional spacing of 6 x 6 ft requires thinning after about 20 years in order to maintain good growth. The more modern spacing of 8 x 8 ft does not require thinning until trees are about 5 ft 7 inches in diameter at breast height.

To reduce the cost of thinning in commercial plantations, specialized chemical applicators have been developed. The cut surface method, or "hack and squirt" application is widely used. Oil cans or plastic squeeze bottles are used to apply 1 to 2 ml of herbicide into a frill or axe cut. Various commercial tree injectors are available to meter in a predetermined shot of chemical. The Newton Axe or hypo-hatchet injector is new, but is finding favor with some foresters in the Pacific Northwest.

Finnis (1967) reported on trials of various chemicals for thinning commercial forest stands in order to leave dominant trees at a 12 x 12 ft spacing, or about 300 trees per acre. This type of thinning requires killing off about 800 to 1,200 trees per acre. Ammonium sulfamate gave very poor results as did 2,4,5-T amine salt. Promising results have been obtained with both cacodylic acid and picloram in various commercial formulations. Species susceptibility, seasonal effects, extent of flashback and cost reduction are problems requiring continuing study.

Chemical thinning has several important advantages over conventional felling methods. Cost is the major benefit, since chemical treatment eliminates the major task of pulling down cut stems, lowers investment in equipment, improves safety, and eliminates long-distance packing of heavy supplies and equipment. Cost of chemical thinning increases rapidly with increasing density of stems to treat, although not in proportion to the density of the stand. Other important benefits from chemical thinning are the reduction of fine fuel on the ground, stiffness of treated stands against wind and snow, reduction of slash hindrance, protection against sunscald and resistance to insect attacks.

The cost reported by Finnis involved 8 to 10 man-hours, plus chemical costs of $2.50 to $7.10 per acre, depending on the chemical used. Thinning with power saws in comparable stands took twice as long per acre; saw-rental cost for the increased time was more than the chemical cost.

Chemical Processing before Harvest

Depletion of virgin timber stands has already shifted most of the forest industry from old-growth to young-growth utilization. Second-growth stands yield low volume per log. Two relatively new methods are being studied which may make the harvest of smaller trees more attractive economically: (a) chemical killing of trees to permit air drying of standing timber before logging, and (b) "sour-felling" or cutting the trees normally, but leaving them untrimmed and unbucked to dry by transpiration from the untrimmed and live crown (not widely used in the United States).

The introduction of reliable "one-shot" silvicides has renewed interest in chemical killing. Sodium arsenite, which has been used in killing and debarking pulpwood, often gives unpredictable kill accompanied by backflash.

Cacodylic acid as a potential one-shot silvicide was reported by Smith (1965). More recently Holt and Newton (1967) have compared sour-felling and chemical killing under a variety of conditions. Trees were treated with cacodylic acid applied to axe cuts with an oil can. Trees treated in November began to show effects within two months, the tops thinning as defoliation took place from the top downward and from the branch tips inward.

The trees killed in the fall were 22% percent drier and 10% lighter than control trees. This weight reduction permits a legally loaded truck to haul an extra 720 bd ft per truckload.

Other Uses of Herbicides

As a maintenance tool, herbicides are used for establishing firebreaks (Bovey and McCarty, 1965), for roadbuilding and roadside weed control, suppression of understory vegetation, and control of noxious plants. The special role of herbicides in improving forest wildlife habitat will be discussed in a later section.

Herbicide Effects on Forest Ecology

All forestry uses of herbicides have one element in common: The destruction of certain plants or species within the treated area. The most common objective is to minimize competition, accelerating growth of existing trees on the site, or to improve site conditions to a degree which will allow reforestation.

A forest is a community of trees, shrubs, forbs, grasses, birds, mammals, mollusks, arthropods, and microorganisms, living together in an abiotic environment of air, soil, sunlight and water (climatic and edaphic factors). The vigor and welfare of the organisms are dependent upon the factors of the environment surrounding them; and the environment itself is regulated to a considerable degree by the biotic community. Together these biotic and abiotic factors form a complex and interdependent ecological system in which each factor and each individual is conditioned by the others, and to some degree affects others in the ecosystem. Such a complex never does and never can reach any balance or permanence; it is constantly changing.

When any environmental factor is changed or any species are eliminated from the community, inter-related changes occur as a chain reaction throughout the system. Many of these changes can be obscure or long-term effects difficult to foresee, but the end result may completely negate any short-term benefits. Successful manipulation of plant-species composition on forest lands depends upon a knowledge of the ecology and the dynamics of competing vegetation. One or more undesirable species of shrubs or brush may be eliminated, only to have the space occupied by even less desirable plants. The sometimes unavoidable removal of preferred browse or forage plants may cause animals to turn to young conifers as a substitute. Killing the dominant vegetation, or modifying the composition of a plant community by removing some components, can alter the abiotic factors of the environment as well.

The ways in which herbicides alter forest dynamics have been studied by a number of investigators. Newton (1967) reviewed the response of forest communities to manipulation. Certain differences between normal plant succession and man-caused succession in desert, savannah, temperate forests, and rain forests were described.

Vegetation management, most commonly, attempts to control succession by application of broad-spectrum herbicides or by selective weed-control practices. Only a few general response principles can be applied to all types of vegetation. A primary concept, however, is that disturbances promote undamaged vegetation to the detriment of the damaged species. Species favored by herbicide treatment will tend to remain dominant longer than in a normal succession. It is always true that species resistant to herbicides make up a larger and larger component of communities subjected to repeated applications. Unplanned increases of undesirable components may often serve to complicate further control measures.

In his discussion of temperate forests in which trees totally dominate the plant community, Newton (1967) summarized some of the effects of herbicides:

> "Manipulation of herbaceous or shrub components of mature (forest) communities has relatively little impact on the total

vegetation, and return to equilibrium conditions may involve little change. Removal of trees only, however, will result in rather rapid release of growth by herbs and shrubs. Some understory shrubs have a great capacity to respond to release. Treatments that favor such species are effective in restricting re-development of trees as well as herbs.

"Herbaceous species developing after devegetation in the more droughty zones of the temperate forest region are capable of intensifying the drought conditions to the exclusion of seedling woody associates.

"Woody species require substantially more time for their establishment and emergence as dominants in a community than herbaceous species. The course of succession following total devegetation on temperate forest sites may differ completely in the presence or absence of livestock or browsing animals. Animals browse preferred species, and trample any species. While it is not safe to generalize as to the preference of animals for certain classes of plants, heavy use by animals tends to trample or retard woody species to the advantage of herbaceous species. Thus the effect of a broadcast spray that suppresses shrubs and tree species can be expected to last much longer in terms of persistence of the pioneer herbaceous vegetation if animals are present than if they are absent. This may not be desirable in reforestation, however, because noncommercial species may escape animals sooner than valuable trees.

"One of the most common forms of selective vegetation control in temperate forests is that of thinning, or stand improvement by killing undesirable stems. This practice differs from other disturbances in that the overstory remains intact, although some species may be eliminated from the dominant canopy. In this way, the course of succession is changed somewhat because some species may not be represented in climax or subclimax forests that develop. Response to thinning by understory vegetation, and the duration of its existence, is proportional to the amount of site released. Under such circumstances, animals will probably have little to do with the course of subsequent succession, except insofar as they may restrict development of coppice. A short term of succession in the presence of animals is apt to ensue, however, because of the increase in attractive forage species that usually accompanies an opening in the forest canopy. Animals can have little to do with forest succession after this, however, because dominant members of the overstory are inaccessible, hence not subject to manipulation by their feeding activities."

Plant-animal interactions within the ecosystem may also affect competition between two plant species on forest lands. Selective browsing of trees and shrubs is an important factor in competition between conifers and brush species throughout the Pacific Northwest. Where rabbits, big game, and other animals are apt to be a problem, users must take care not to eliminate preferred browse species from the community, for the animals may turn to conifers as a substitute.

Already, browse species have been seeded experimentally on some areas in California (Baron et al., 1966) and in the Pacific Northwest in an effort to reduce browse pressure on conifers. Deerbrush ceanothus (<u>Ceanothus integerrimus</u>) and redstem ceanothus (<u>Ceanothus sanguineus</u>), recognized as excellent browse species, have been seeded for this purpose on forest lands. On sites where preferred browse species have grown to heights which are no longer available to animals, herbicides have been used to decrease height of live crowns and increase basal sprouting of the shrubs. Observations of aerially sprayed sites on forest lands in the Pacific Northwest indicate that big game and other animals prefer tender, new basal sprouts of many brush species rather than the mature plants.

Effects of Herbicides on Forest Environment

The use of herbicides to manipulate the composition and structure of vegetation on forest land constitutes a disturbance of the forest ecosystem. Disturbances within the forest, according to Spurr (1964), can be grouped into three classes:

(1) Disturbances altering the structure of forest; including fire, windthrow, logging, and land-clearing activities.

(2) Disturbances altering the species composition of the forest; such as the elimination of plants and animals from the forest ecosystem or the introduction of new plants and animals into that system.

(3) Disturbances altering the long-term climate in which the forest grows, or climatic shifts which affect the vigor and competitive ability of the species making up the forest.

Herbicides, as used in forest management obviously do modify the floristic composition of the plant community (a disturbance of the second class), but a less obvious and perhaps more important effect is the indirect action of herbicides on the climate, soil and water of the forest environment.

Some of the mechanisms by which herbicides can alter the ecology of forests have been described by Gratkowski (1967). Among the major factors affected by herbicides are the energy balance of the forest, including the quantity and intensity of solar radiation; the quality and wavelength of light within the forest, and the black body radiation characteristics of the vegetation and soil.

When the dominant vegetation is killed, or when the composition of a plant community is modified, herbicides may change abiotic factors of the environments as well. Macroclimatic factors such as annual or seasonal distribution of precipitation, solar radiation, wind, and other atmospheric conditions, are not readily modified. Microclimatic conditions within a brush community, however, can be modified by changes in structure or composition of vegetation. Killing all vegetation on the site, or thinning a dense stand by eliminating some of the dominant plants increases the amount of solar radiation received per unit area at lower levels. In addition, it also changes the spectral composition of light received by species in the lower levels. Concomitant effects are higher air and soil temperatures, increased windspeeds and air movement, decreased relative humidity, and decreased interception of precipitation. In turn, these can lead to changes in edaphic factors such as increased soil temperatures at surface and subsurface levels, increased soil moisture, and increased activity of soil microflora and microfauna leading to more rapid decomposition of organic matter.

Releasing conifers from a brush overstory results in major changes in microclimatic conditions for the trees. Changes in light conditions are especially important. Released conifers receive far more direct sunlight, light intensity is increased, and light quality is enriched in both the ultraviolet and infrared ends of the spectrum. Use of soil moisture and nutrients will be reduced, leaving more water and nutrients for the conifers and other surviving vegetation. Amounts of additional water and nutrients actually available to the conifers, however, will depend upon root characteristics of both the conifers and other vegetation rooted at the same depth and the inherent ability of each to compete for the available materials.

All effects may not be beneficial to the forest. Heat losses to the atmosphere will also be increased. As a result, diurnal variation in both environmental and plant temperatures will be increased, and the newly exposed trees may be more subject to late spring or early fall frosts than they would have been under a brush cover.

Numerous investigators have reported the influence of changing or manipulating forest vegetation on both the microclimatic and macroclimatic factors. Fons (1940) and Reifsnyder (1955) have documented the influence of forest cover on wind velocity; while Marston (1956) has studied air movement in an aspen forest as compared with adjacent openings. The influence of pine forests on the daily temperature has been reported by Miller (1956); and Fuller (1948) has compared carbon dioxide concentrations in the atmosphere above forest and rassland.

Perhaps the most important effect on the forest ecosystem produced by vegetation control measures is change in forest hydrology. Approximately two-thirds of all the rain falling in the continental U. S. is returned to the atmosphere by evapotranspiration processes. The management of forest hydrology centers around modifying the arrangement and composition of vegetative cover to control retention and release of water.

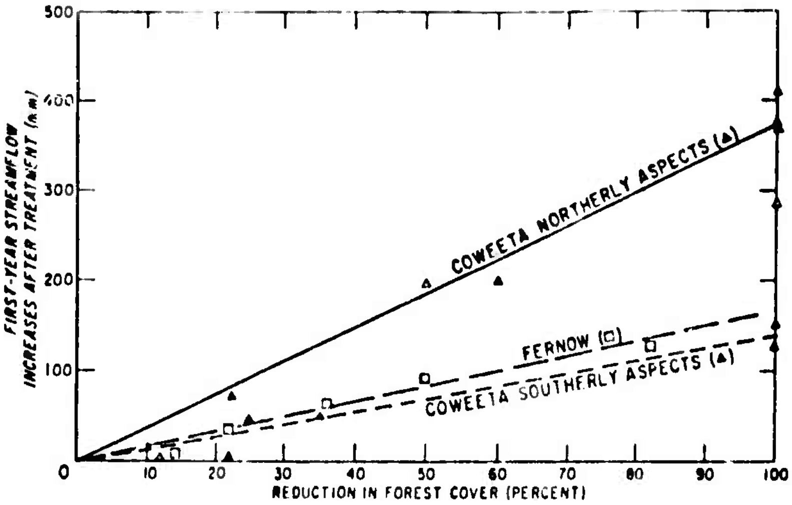
There is world-wide interest in better understanding of forest hydrology as shown at the international seminar sponsored by the National Science Foundation in 1965. The principal research interests at this symposium (Sopper and Lull, 1966) dealt with studies of the interception of precipitation by forest trees and stands, the relationship of different kinds of vegetation to residual soil moisture, the ability of soils to absorb and discharge precipitation of different amounts and intensities, measurement and calculation of evapotranspiration, study and prediction of total and seasonal streamflow, and the influence of vegetation on the erodibility of soils in forest watersheds.

Research in the U. S. is largely directed toward water yield improvement, watershed protection, watershed rehabilitation, and forest soil development and improvement.

Hibbert (1966) has reviewed the effects of modifying forest vegetation by various treatments on water yield. Some studies included the use of silvicides to destroy trees in varying patterns, and the repeated application of herbicides to remove chaparral. Water yield increases are directly related to the extent of cover removed rather than to the method used for controlling vegetation. Figure III-C-2 shows typical first-year streamflow increases from various test areas as a function of the extent of forest cover removed.

The linear relation between the percentage of the area devegetated and the amount of streamflow increase appears to hold for other investigations conducted throughout the world.

Pereira (1966) summarized watershed management and streamflow studies, pointing out that understory shrubs and sprouts in the Coweeta Test reduced the water yield only one-third more than did the clean-tilled vegetable crops at Kimakia. It appears probable that the extent of water yield increase that can



Source: Hibbert (1967).

Figure III-C-2 - Forest Lands, Properly Managed, Represent Valuable Resources for Timber, Wildlife, Water Supply and Recreation be obtained in general forestry practice, where clean cultivation is uneconomic, will usually be less than 40%. These empirical results generally agree with the energy balance theories advanced by Penman (1963). In a series of tests reported by Penman (1966), four different types of forest cover in widely separated geographical regions of the world gave energy-balance equation constants which were in fairly good agreement.

Disappearance of Forest Herbicide Residues

Possible problems of herbicide residues in forest soils have been studied by a number of investigators. With the most commonly used chlorophenoxy herbicides at the presently used levels of application, accumulation in the soil does not appear to be a serious problem. A later section of this report will cover residues in detail (Chapter VII). A review article by Sheets and Danielson (1960) gives several references to the degradation of chlorophenoxy herbicides in soil. Other reports by DeRose and Newman (1948), and Brown and Mitchell (1948) deal with degradation of chlorophenoxy herbicides by soil microorganisms. Norris (1966) reported the degradation of 2,4-D and 2,4,5-T in forest litter using carbon-14 labeled compounds. Results show that more than 85% of the 2,4-D was decarboxylated in 300 hr; while less than 25% of the 2,4,5-T was broken down in the same period. Practical studies of the extent of herbicide residues monitored in forest streams following herbicide application have also been conducted by Norris (1967). Nearly all of the herbicide found in the streams result from the direct application of spray materials to the surface of the water. Within a few hours after spraying, the levels of herbicides found in the streams fell to levels well below 100 ppb, tentatively believed safe for fish and aquatic life.

Long-term Ecological Responses

Little information is available on the long-term ecological responses of vegetation following aerial application of phytocides. A few localized studies have been completed, but these are generally of a short-term nature, with data collected only two or three years after treatment. However, systematic observation has seldom been made over a period of five or more years.

Not many studies have focused special attention on the ecological responses to phytocidal treatments in terms of what has happened over a period of more than one or two years. Studies by Hansen (1955, 1956) report stand changes over an eight-year period following application of 2,4-D in a mature mixed aspen-birch stand with scattered old white pine veterans and a heavy brush canopy. At the end of this period, the brush canopy as measured by either height or number of stems was still far below that on the untreated control plots, and white pine regeneration was more abundant and of larger size. There was an immediate and large post-application increase in the abundance of raspberry. In the herbaceous cover, bracken fern increased and sarsaparilla markedly decreased in abundance following spraying. Increases in grasses and sedges were also noted.

Bramble, et al. (1967) reported on the changes in structure and general composition of hardwood forest cover from 1953 to 1967. The study was made on Pennsylvania utility line rights-of-way subjected to a variety of phytocidal treatments. The original forest cover consisted of trees, a tall shrub cover of 54% density, and a ground cover of bracken, sedges, herbs, and blueberry which was present largely in the openings under the tree and tall shrub overstory. Basal application of 2,4-D and 2,4,5-T greatly increased the ground cover density to over 80%, and did not disturb its composition as a result of eliminating the tall shrub and tree cover. On the other hand, broadcast foliage types of treatment drastically changed the cover to sedges and grasses with a density of coverage averaging 96%. A broadcast foliage application of ammate produced even more drastic change in ground cover to sedges, fireweed, and bracken over 85% of the area. Areas given broadcast applications tend to recover slowly reproducing largely the original kind of vegetation. Selective basal spraying is reported to make possible the elimination of tree and large shrub cover and maintenance of the area in that condition by occasional retreatment.

A study of long-term vegetational changes following aerial application of 2,4-D and 2,4,5-T in northern Minnesota was reported by Schacht and Hansen (1963). This study reports the changes in tree canopy, changes in the species of herbs, changes in the grass-sedge canopy, and changes at the forest floor. The implications for forestry applications and some implications for wildlife considerations are also discussed.

Wildlife Effects of Forest Herbicides

There are several ways in which the use of herbicides can be expected to supplement other forestry practices for the improvement of habitat for wildlife. They are of particular importance where it is not feasible to improve habitat through commercial timber operations. Herbicides are used for making and maintaining openings or clearings in forested areas and for increasing browse. Lindzey (1960) reported that herbicides can be used in the selective removal of competing plants in order to favor food producers or to make way for seeding and planting food and cover plants.

In aerial release work, Arend and Coulter (1955) suggested methods for maintaining wildlife habitat. They recommended that when areas in excess of 40 acres were to be sprayed, unsprayed strips 30 to 50 ft wide should be left at 10 chain intervals parallel to the flight line. It was also suggested that the vegetation along the stream banks be left unsprayed.

In Michigan, considerable acreage of worthless aspen has been sprayed with the hope of killing these trees and opening up the areas to provide good food and cover conditions for sharptail and ruffed grouse (Roe, 1955). Geysel (1957) also reported that release methods used in lower Michigan pointed out that aerial sprays could be used for improving wildlife habitat.

Krefting, Hansen, and Stenlund (1956) found that both hand cutting and stem spraying using 2,4-D produced abundant sprout growth of mountain maple with cutting resulting in the greatest regrowth. Hansen and Krefting (1957) indicated that the results of two years of testing showed that herbicides can be used cheaply and successfully to kill back overgrown mountain maple and induce a healthy regrowth of sprouts which deer can readily eat.

A study by Bramble, Byrnes, and Hutnik (1958) on transmission rights-of-way in Pennsylvania demonstrated that common game species used all spray areas the first year following spraying and either increased their use or maintained it for five years. Considerable disturbances of plant cover, both in amount and kind, followed spraying. Selective techniques maintained the original ground cover composition and increased its coverage. The development of edges and type interspersion through spraying favored such species as turkeys and rabbits. Deer used the spray areas heavily in the spring and summer while grouse appeared to prefer the wooded edges.

Ammann (1957) and Van Etten (1959) indicated that herbicides are valuable in managing prairie-grouse habitat. Aerial applications of 2,4-D at 2 lb/acre were used to create openings in dense aspen and willow stands. Heavy sprouting of valuable deer food species followed the treatments. A disadvantage of this type of operation was that certain desirable plants may be selectively eliminated, and too little edge may be preserved.

A study in Virginia (Trumbo and Chappell, 1960) was designed to appraise the economics of creating wildlife openings with herbicides in inaccessible oak woods. It was found possible to reduce the amount of chemical to as little as one-tenth of the original amount used and still get practically the same kill. Two years after treatment, seedling and sprout growth in experimental plots proved highly attractive to rabbits and deer.

Krefting, Hansen, and Hung (1960), and Drefting and Hansen (1963) have been successful in releasing preferred browse plants by aerial application with 2,4-D ethyl ester at 2 lb/acre. This study was conducted on the Tamarac National Wildlife Refuge in Minnesota. The authors indicated that the phytocide was selective in killing the low preference species of browse plants. At the end of two years there was a considerable increase in the total number of stems on all cover types treated. The cost per acre for these sprayings was approximately $3.50.

It has been found that 2,4-D and 2,4,5-T are not toxic to game animals (Arend, 1959). George (1960) stated that many herbicides are only slightly toxic to wildlife and can be used at effective dosages without serious immediate effects on wildlife or food-chain organisms. Other compounds (such as dinitro compounds, sodium arsenite and pentachlorophenol) are toxic to wildlife and invertebrates, and their use can present hazards unless great care is taken in their application and consideration is given to toxicity thresholds. There is some poisoning hazard to wildlife when formulations or materials designed for upland or terrestrial areas are used in lowland or aquatic areas. In general, however, most herbicides can be expected to have no serious direct effects on wildlife.

Indirect toxicological effects on wildlife through destruction of food-chain organisms have received little study. More research in this area needs to be conducted on a long term basis.

Indirect or secondary effects of herbicides on wildlife through habitat change could be great. Care must be taken in planning the overall application in any large scale operation. In general, those applications that tend to make the environment more uniform will eventually lower wildlife populations; whereas those that tend toward diversity, such as opening up areas in a forest community, will tend to increase wildlife population.

In summary, herbicides can be used effectively and selectively in wildlife habitat management. Continued research is needed to determine the best chemicals to use, proper application methods and the subtle but far-reaching interactions between wildlife and habitat. Herbicides cannot be considered a cure-all, but a tool to be used at the right time, place and in the right way.

The use of chemicals in general offers a more efficient and economical method of habitat management than techniques formerly used. As herbicides formulations, equipment and techniques have been improved, the cost of managing vegetation in wildlife areas has decreased and even greater effectiveness and reduced cost may be expected.

D. Herbicide Application on Rangeland

The development and maintenance of adequate rangeland for the grazing of domestic animals is one of the chief problems of the agricultural industry. The United States is the world's leader in advanced agricultural technology. This country, along with Australia, New Zealand, and Argentina and other countries in South America and Africa, has expanded their efforts in grass and ranchlands research. The monetary value of such investigations and the resulting improvements are not easily calculated, but the increase in land utilization represents millions of dollars in the United States alone. The benefits to other nations and in particular to the lesser developed nations, provide additional impetus for bringing about better management of the range lands of the world. Basic to range development, improvement and maintenance is adequate weed and brush control.

Historical Background

The significance of weed and brush control has long been recognized but constant changing of man's use of his environment has altered the rangeland and the interrelationship of plants and animals in such areas. Also, the need for additional food,clothing, etc., from agricultural sources has constantly been increased due to the human population growth.

Indications of the extent of the problems involved in weed and brush control have been mentioned by Herbel (1967) Turner et al. (1963), and many others. Approximately half of the total land area of the United States is used for pasture and grazing, and weeds and brush are a problem on nearly all of this area. Table III D-1 taken from Herbel's publication (1967), lists the enormous number of acres containing undesirable woody species in the Western United States. Turner et al. (1961, 1963) reported that over 700,000 acres of Idaho, and 2,000,000 acres of Oregon were plagued by infestation with the range weed grass medusahead.

In each of the cited publications the authors indicate that the acreage of undesirable woody species increases at a rapid rate and that the real problem is to control the extent of brush and weed grass invasion of yet uninfested areas. This spread of brush is documented in the publications of Herbel (1967), in which data on the Jornada Experimental Range is summarized. Mesquite dominated 4.8% of the area in 1858 but this increased to 50.3% of the area by 1963. Correspondingly large increases occurred with woody species during the same period; however, the type of brush invasions varied with the different types of soil available on the range.

TABLE III-D-1

OCCURRENCE OF SOME UNDESIRABLE WOODY SPECIES IN THE WESTERN U. S. (PLATT, 1959)

	Million Acres
Sagebrush (Artemesia Spp.)	87.4
Rabbitbrush (Chrysothamnus Spp.)	4.9
Tarbush (Flourensia Cernua)	13.3
Juniper (Juniperus Spp.)	63.9
Creosotebush (Larrea Tridentata)	46.5
Cactus (Opuntia Spp.)	78.6
Mesquite (Prosopis Spp.)	93.0
Scrub Oak (Quercus Spp.)	40.3
Yucca (Yucca Glauca)	2.0

Source: Herbel, C. H., Brush Control in New Mexico, Jornada Experimental Range, Crops Research Division, ARS, USDA (1967).

The scope of the weed problem on grazing land is constantly changing with the introduction of new plant species and with the shift of dominant species from forage to nonforage types. Spread of mesquite in Texas was attributed to the passage of viable seeds through horses, cattle and sheep. Thus, changes in vegetation on range and noncropland are occurring due to the influence of grazing practices, cultural manipulations, plant introductions, diseases, insects, various other fauna, and many environmental factors.

Weed control on rangeland in countries other than the United States presents similar problems, except the prevailing species are different. For example, Brazilian pastures are infested with Leiteiro, Amendoin, Acacia, and numerous other brush weeds (Quinn et al., 1956).

The dominance of weeds, both brush and weed grasses, may be controlled, changed, or prevented by the use of mechanical, chemical and biological methods. Frequently combinations of these methods are used and these will be more fully described in the next section. However, factors such as climate, native plant and animal life, soil conditions, moisture, and temperature may materially influence the results of attempted range improvement programs. Some land areas may not respond favorably to treatment, yet many forage lands can be made more productive by appropriate weed control programs.

Fisher* expressed the belief that about 20% of the Rolling Plains with mesquite and other undesirable brush can be profitably used for forage and other cultivatable grazing crops. Another 20% of the study area was too shallow and otherwise unsuitable for development into grazing land. The remaining 60% of Rolling Plains is not suitable for cultivation but can produce good grass if brush is controlled. Although other rangelands may not be similar to the areas reported by Fisher the facts are still impressive that weed control will be beneficial in many ways, including economic return. Yet in spite of the work already undertaken, we have vast opportunities for extension of the various forms and methods of weed control.

Current Herbicidal Control Procedures for Rangeland

Brush and weed control methods vary greatly due to terrain, soil conditions, type of weed infestation, purpose of land use, and above all on the cost of land treatment. Control measures include chemical, mechanical, manual, burning, biological and selective grazing of the range. In actual practice a single method may be used but frequently combinations of methods are employed to an advantage. Better results usually follow sequential or appropriately timed utilization of two herbicidal treatments regardless of whether they are of the same general type or different.

The objective of herbicidal treatment of range is rarely the eradication of brush; the goal usually is designed to control or regulate the problem weed species; thereby permitting the development or utilization of the forage for improved grazing conditions. Brush control is particularly difficult in some species due to their capacity of regenerating vegetatively. Klingman (1962) states "our most urgent job in brush control is to find a way to kill dormant buds."

Mechanical Methods

Mechanical methods of control include hand chopping, cabling or chaining, bulldozing, grubbing, root plowing, and disking (Herbel, 1967). Cabling or chaining is simply a process of pulling a long heavy cable (usually destroyer anchor chain) between two large tractors traveling parallel. It is effective on fairly level ground with 3 inches diameter brush from nonsprouting species but is not generally effective on small plants and sprouting species. In mesquite country chaining is used a year after herbicide kill to pull down the snags and tear out the crown root.

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* Personal communication from C. E. Fisher.

Bulldozing is a good method for controlling larger trees. Modification of the dozer blades can be done so that grubbing can be effective on relatively sparse stands of brush but such operations must be followed by seeding or only be used where there is good residual grass stand after the bulldozing operation.

Root plowing is effective in controlling brush on deep soils which are free of rocks and obstructions. A special plow blade (a stinger) is usually used to individually push or snag the roots out of the ground and thereby prevent their resprouting.

Disking for brush control is limited to plowable soils and small shallow rooted plants. It is basically similar to rootplowing except that brush is destroyed by pulling a single disc plow or tandem disc over the field. Disc treated range must be reseeded since much of the grass is destroyed.

Hand chopping of brush is effective and cheap but only for small sparse stands of brush. It is more helpful in preventing invasion of range than in eradication of heavier brush growths.

Burning Methods

The use of fire for weed control is practiced but this is more applicable to the unpalatable weed grasses rather than brush. Turner et al. (1963) have discussed the advantages of fire for control of medusahead. It is cheap, can be applied to rough and stoney areas, destroys seed crops (weeds) before maturity and reduces litter which is capable of preventing good growth of desirable grass. The dangers of fire in weed control are obvious and include the destruction of valuable good range, crops, homes, etc. Fire does not always destroy all the viable seeds of medusahead; thus fire control of weed grasses is often followed by other control methods such as chemical treatment of the infested area. Herbel (1967) states that burning may also be used to control several kinds of undesirable range shrubs such as big sagebrush, burroweed and brown snakeweed; yet the burning must be done at the proper season, under proper moisture conditions, appropriate grazing management, and adequate precautions.

Biological Control Methods

Biological weed control methods are mentioned in the literature, yet such methods are not considered as a single means of control. This is a field for considerable basic and practical research which will undoubtedly be given a great deal of investigation in the future. The biological methods may be used for preventative control and correction of existing conditions.

Turner et al. (1963) referred to the work of Lusk et al. (1961) in control of medusahead by heavy grazing of sheep during the spring with a resultant thinning of the weed stand. Such a practice would have to be followed with a period of no grazing to permit the resident perennials to mature.

Leaf-feeding beetles of the genus Chrysolina and a root borer were used to parasitize the perennial weed, St. Johnswort, and their use was followed by a reduction of the weed to 1% of its previous California level (U. S. Department of Agriculture, 1966).

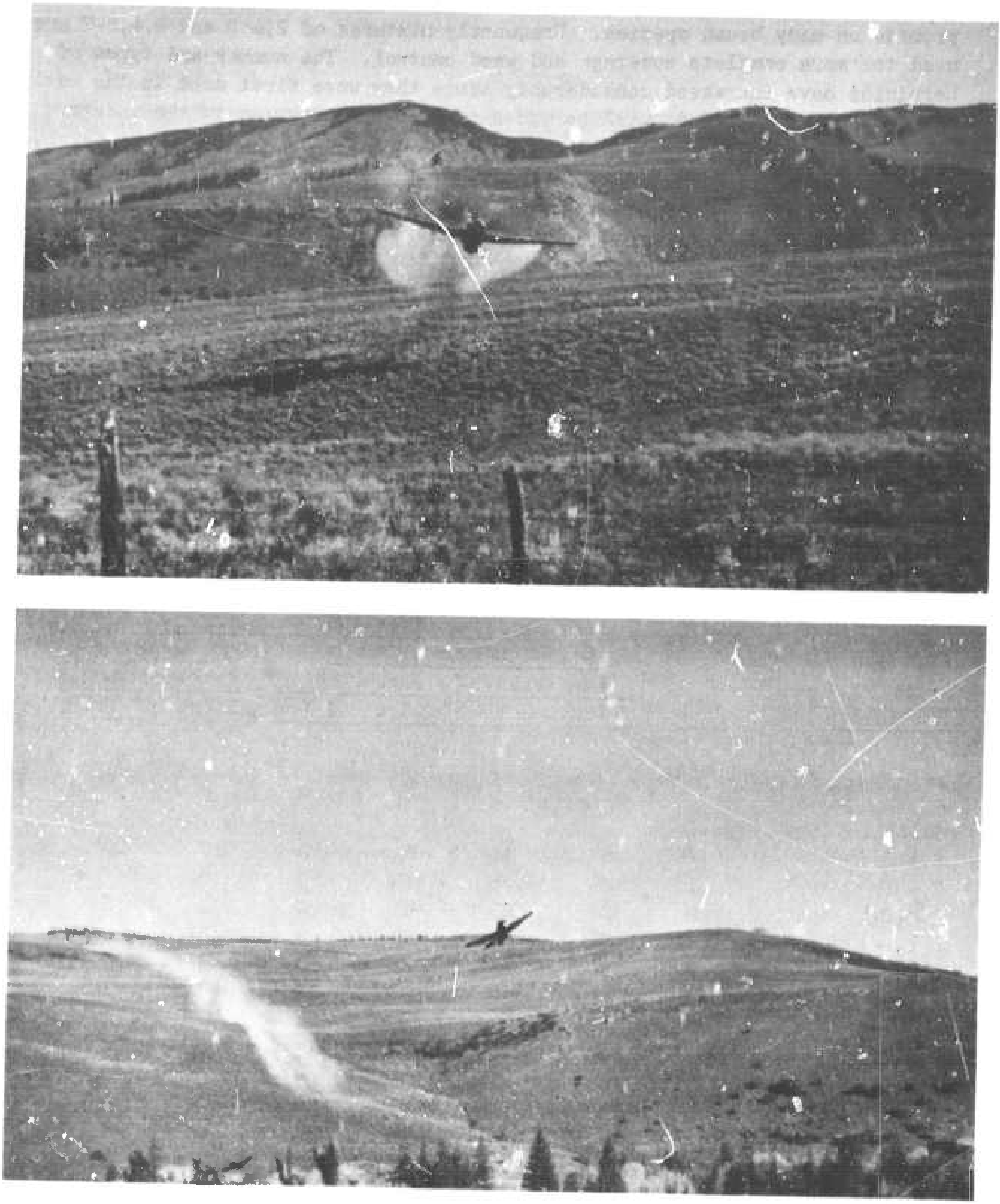
Following many of the forms of mechanical, chemical, and burning techniques of weed reduction, it is necessary to reseed with good range grass. This reseeding is a biological control procedure since the seeded plants may grow sufficiently fast and provide sufficient ground cover to prevent the regrowth of weeds.

By controlling the grazing patterns of animals the spread of weed seeds may be prevented. Leith (1959), stated that changing weed patterns depend upon the distribution of dung patches. Thus, if animals are prevented from moving to new grazing areas after feeding on infested range, one form of weed distribution may be prevented. However, this is not practical since the wild animals are not restricted.

Chemical Methods

Herbicidal chemicals have been developed for numerous plant species and application of the materials has resulted in good, and in many cases, outstanding control of noxious weed grasses and brush. Systemic herbicides are generally applied by foliage sprays, either from ground or aerial units, Figure III-D-1. However, some agents are applied to the soil around the bushes or directly to the plant stem or cut stump.

Application of the herbicides must be made at the proper stage of plant growth. Also, a number of factors such as moisture, temperature, soil conditions, spray droplet size, etc., influence herbicidal action. Failure to take into consideration the stage of growth and these other factors may materially reduce if not eliminate the effectiveness of these agents. The best chemical and conditions for weed control must be determined for each plant species to be controlled.



Courtesy of Aerial Applicators

Figure III-D-1 - Aerial Application of Herbicide on Rangeland

For brush control of a variety of plant species 2,4-D, 2,4,5-T, silvex and the phenoxy compounds have been used. Picloram has also shown promise on many brush species. Frequently mixtures of 2,4-D and 2,4,5-T are used for more complete coverage and weed control. The number and types of herbicide have increased considerably since they were first used in the early 1940's and new compounds will be added to the armamentarium in the future.

Single aerial application of 2,4-D; 2,4,5-T; and a 1:1 mixture of the two gave excellent control of sand sagebrush in Western Nebraska (Bovey, 1964). An excellent top kill was obtained but regrowth occurred and for best results repeat applications were necessary the second year. In the same study silvex (a phenoxy herbicide) gave excellent control following a single application. Table III-D-2 illustrates the data obtained with the various compounds and lists the rates of application. One pound/acre of 2,4-D applied for two consecutive years gave 95 and 100% control.

TABLE III-D-2

INITIAL LEAF KILL AND SUBSEQUENT REGROWTH OF SAND SAGEBRUSH AFTER SINGLE AND REPEAT APPLICATIONS OF PGBE ESTER FORMULATIONS OF 2,4-D, 2,4,5-T, 2,4-D PLUS 2,4,5-T AND SILVEX IN DIESEL OIL AT 5 GPA

Location and Herbicide	Rate	Time after Application: Single: Leaf Kill 3 Mo.	Leaf Kill 1 Yr.	Regrowth[a] 2 Yr.	Regrowth[a] 3 Yr.	Repeat: Regrowth 1 Yr.	Regrowth 2 Yr.
	(Lb/A)			(%)			
Alliance							
2,4-D	1/2	57	45	80	83	17	50
2,4-D	1	86	35	70	50	13	7
2,4-D	2	96	25	60	60	7	3
2,4-D + 2,4,5-T	1 + 1	97	20	63	40	3	0
2,5,5-T	2	98	40	53	60	0	0
Silvex	2	99	22	20	23	7	3
Haigler							
2,4-D	1/2	90	72	73	43	10[b]	0
2,4-D	1	100	57	23	27	0	0
2,4-D	2	100	55	60	50	0	0
2,4-D + 2,4,5-T	1 + 1	100	67	57	33	0	0
2,4,5-T	1/2	100	62	67	80	0	0
2,4,5-T	1	100	57	53	60	0	0
2,4,5-T	2	100	52	70	70	0	0

a/ Percentage kill is the inverse of percentage regrowth; it can be derived by subtracting percentage regrowth from 100.
b/ The 1/2 lb/A 2,4-D treatment at Haigler was retreated with 1 lb/A.
Source: Bovey (1964) p. 255.

Mitich (1965) reported that a number of weed and brush species were controlled by two 2 lb/acre applications of 2,4-D. The species included buckbush or western snowberry, goldenrod, fringed sage, gum weed, prairie thistle, silverberry and tall prairie astor. He also reported good control of annual weeds with one 1 lb/acre 2,4-D treatment.

Studies with yucca control by aircraft applications revealed that silvex applied at 2 lb/acre in No. 2 diesel oil at 5 gpa (gallons per acre) total spray solution gave the best yucca kill (Bovey, 1964). However, a substandard amount of regrowth was found in all plots two years after treatment; therefore, retreatment is necessary for best control.

The extent of the mesquite problem on rangeland was mentioned earlier in this report; therefore the observations that the ester of 2,4,5-T was superior to the amine form of the compound for the control of mesquite are important (Roach and Glendening, 1956). Percentage plant kills ranged from 5 to 65 depending upon the study site. Top kill of the mesquite averaged 75.8% and ranged from 58-91% in the various sites. Differences at the various sites may be evidence of genetic differences in plants, soil variations, or climatic differences accompanied by differences in plant development. The lower ratio of plant kill to top kill emphasizes the need for repeat treatments with herbicide and also illustrates the extreme difficulty encountered in bringing about eradication of weed brushes. Thus, the procedures are generally for <u>control</u> rather than eradication.

Gantz and Laning (1963) reported good field responses with a number of woody plants to both 2,4,5-T and to 4-amino-3,5,6 trichloropicolinic acid; however, the latter compound was more effective. Test plants included poison oak, manzanita, chamise, coffeeberry, mountain misery, macartney rose, mesquite, prickly pear cactus, and huisocke.

Favorable seasons must be chosen for certain plants to be effectively controlled. Hyder et al. (1958), found that a favorable season as well as susceptible stage of plant growth were necessary for the proper timing for the control of rabbit brush. Dry range sites may never permit the control of green rabbit brush even though it is susceptible to control with 3 lb/acre of 2,4-D esters when adequate moisture is present.

Although (as pointed out earlier) mesquite is a major range problem on approximately 70 million acres in the Southwest and several million acres have been treated with herbicides; various factors influence the results of such treatments. Fisher et al. (1956) summarized these factors in their paper as follows:

"1. Effective and economical control of mesquite is dependent on translocation of a toxic amount of 2,4,5-T from the foliage to sprouting tissues of the crown.

"2. Leaflet and field plot studies show that greatest translocation of 2,4,5-T occurs generally during a 50 to 90 day period after the first leaves emerge in the spring. This period is considered to be the most favorable time to treat mesquite with 2,4,5-T.

"3 Maximum translocation of 2,4,5-T appears to take place when the total sugar content in the roots is building up at a rapid rate following the low level at the full leaf stage.

"4. Minimum translocation of 2,4,5-T appears to occur when total sugars in roots are decreasing rapidly and reducing sugars are relatively abundant.

"5. The most effective kills of mesquite have been obtained with 2,4,5-T when there was an adequate supply of soil moisture to develop a uniform heavy foliage cover and 2,4,5-T was applied after rapid growth of new leaves and stems had ceased.

"6. Effectiveness of 2,4,5-T aerial applications was reduced when drought restricted growth or intermittent rains caused irregular growth of foliage.

"7. Greater effectiveness of 2,4,5-T was obtained on sandy loam and deep sandy soils than on heavy clay soils and on small plants with stems less than 3 inches in diameter than on larger trees.

"8. Carriers, whether oils alone or oil-water emulsions or water alone, had no apparent influence on the effectiveness of 2,4,5-T applications when used at 4, 8 and 12 gal/acre.

"9. A rate of 1/2 lb. acid of a low volatile ester of 2,4,5-T in 1:3 oil-water emulsion gave effective and economical kills of mesquite. Increasing the amount of acid did not improve the kill of mesquite.

"10. Droplet size of spray material, formulations of 2,4,5-T and weather factors did not appreciably affect the apparent effectiveness of 2,4,5-T. However, these factors must be taken into consideration from the standpoint of safety and ease of handling the herbicide under field conditions."

Herbel (1967) also indicated the importance of translocation in the herbicidal action and he points out that, in some dry years, spray treatments should not be made at any time. Plants under moisture stress do not translocate the phenoxy herbicides; therefore, they are inefficient if not ineffective.

Soil treatment with herbicides gives good control of trees especially applied on an individual basis. Several chemicals have been used successfully in recent years including fenuron, monuron, benzoic acids and combinations of these with other herbicides (Klingman, 1962). Fenuron (25%) pellets and an 80% monuron powder have been found to be effective in controlling brush (Herbel, 1967). Fifty-three to 95% kills of mesquite were obtained with monuron powder and 67 to 94% kills with fenuron pellets. The herbicides were applied by horseback and on foot at a rate of 1 g active ingredient per foot of plant canopy diameter.

Recommendations for herbicide control of New Mexico brush species listed by Herbel (1967) are tabulated below as an illustration of the variety and levels used for single applications.

AERIALLY SPRAYING BRUSH (PER ACRE)	
Big sagebrush	2 lb. 2,4-D
Sand sagebrush	1 lb. 2,4-D
Rabbitbrush	3 lb. 2,4-D
Juniper	3/4 lb. Picloram
Shinnery oak	1/2 lb. Silvex
Yucca Glauca	2/3 lb. Silvex
Mesquite	1/2 lb. 2,4,5-T

The problems of control of weedy annual grasses on rangeland are complicated by the extremely competitive nature of the weed grasses such as medusahead. Five hundred to 1,000 medusahead plants per square foot are not uncommon (Torrell and Erickson, 1967). Thus, the native forage grasses cannot compete with the medusahead. Control is therefore indicated by a two-step process which includes reseeding of the treated area. Torrell and Erickson (1967) have proposed several procedures such as (a) burning, tillage and reseeding, and (b) burning, herbicide treatment (dalapon, 3 lb/A) and reseeding.

It is also recommended that 2,4-D be sprayed later to control the broad-leaf weeds coming up during the growth of the wheatgrass used for reseeding.

Siduron, paraquat and atrazine are other herbicidal agents used for the control of weed grasses. Atrazine is toxic to perennial grasses; therefore its use may permit the growth of broad-leaved weeds.

Broad-leaved herbaceous weeds are difficult to control yet are serious problems on the ranges. Phenoxy herbicides are utilized for their control and repeated treatments are required combined with improved grazing management, range cultivation and reseeding.

Chemical control of range weeds is indeed a complex ecological problem and involves numerous species of plants. The U. S. Department of Agriculture and the U. S. Department of Interior have long recognized the enormity of the problem and have published a handbook on the "Chemical Control of Range Weeds."* The purpose of the publication was to provide suggestions on the control of range weeds with chemicals.

Some Ecological Aspects of Range Control

Rangeland represents a dynamic system of plants, animals, soils, air, sunlight, etc., and the net effect of the complex activities is constantly changing. A specific rangeland ecosystem in one area of the United States will not be similar to another range area in another part of the country or in some other country. Likewise, any single range at one period of time will be different than at some other time. A range ecosystem is part of a larger bioclimate and changes in the range may be brought about by interactions with the flora, fauna and abiota of other ecosystems. Also induced changes in the range ecosystem will exert an influence on the dynamics of other ecosystems.

Weed problems have been created on grazing lands by the introduction of foreign plant species. Earlier in the report mention was made of the introduction of weed brushes with the spanish horse and change in grazing practices. Torrell et al. (1963) discussed the possible introduction of medusahead from Europe to the U. S. and the rapid migration of this weed into Idaho until it now is found on 700,000 acres of Idaho land. These changes in flora illustrate the change just a few plant species can have on rangelands.

The purpose of herbicidal control is to prevent the trend toward dominance of weed plants at the expense of the forage species. Weed infestation or invasions can be halted or changed (controlled) by judicious use of

* U. S. Department of Agriculture, U. S. Department of Interior, Chemical Control of Range Weeds, p. 14 (1966).

mechanical, chemical, burning, and biological methods such as the introduction of new forage species and by careful control of grazing practices. Unfortunately, not all ranges are subject to improvement. Factors such as soil, climate, native plant species, and animal life may prevent ready improvement measures. Nevertheless, many forage lands may be made more productive by using weed control techniques (as described in the previous sections), a practise which is nearly always the most important management tool employed to bring about improvement in the rangeland and its carrying capacity.

Concurrent with the application of range control measures numerous changes are seen to occur in the ecosystem. Some of the changes are beneficial and some may be detrimental. It is also important to note that apparent immediate effects that are beneficial may be detrimental in the long run. Conversely, changes brought about by herbicides may be detrimental to the grazing for the first year, yet provide a long term benefit to the rancher and the range.

Many ecological changes were presented in the discussion of the history and methods of range control. These need not be repeated but they have emphasized the interaction of various factors in the range ecosystem. Specific illustrations will also be presented in the following paragraphs.

The paper of Cable and Tschirley (1961) indicates that a single application of 2,4,5-T resulted in increased production of grasses and the forbs increased further with successive yearly applications of the herbicide. This increased selective production illustrates the satisfactory change for increased grass production at the expense of the weed, mesquite. Their study also illustrates that herbicides used on more than one occasion produce a more lasting effect.

Unfortunately some uses of herbicides may not be as favorable. Turner et al. (1963) state that there are no known herbicides which control medusahead and are yet free of soil sterilizing activity. Hence, seeding cannot be immediately after the use of such herbicides. Herbicides vary considerably in such residual activity. Dalapon has a short period (several weeks) but atrazine and isocil have long residue soil activity, lasting for at least a year.

Torrell and Erickson (1967) in their medusahead grass control studies found that their multiple weed control treatments created a partial botanical void and the space was <u>not</u> filled with wheatgrass but with rapidly growing annual weeds that originated from dormant, soil-borne seeds. This severe weed competition served to suppress the desired species.

A number of illustrations of altered plant succession as a result of herbicide controls may be described. Hedrick et al. (1966) reported that sagebrush rapidly reoccupied mechanically treated poor condition ranges. Their work also points out that cheat grass is becoming a more important component of poor and fair condition ranges that are treated for big sagebrush and the authors stated that one can expect that improvement and management practices could adversely change the proportion of annuals and perennials.

Johnson's (1958) data on reestablishment of sagebrush in long-term studies indicated that when more than 75% of the sagebrush was chemically controlled by 2,4-D the range remained relatively free of sagebrush seedlings for a four-year period. Similar data were reported by Alley (1956).

Perry et al. (1967) found that 89 to 100% control of chaparral increased the range-carrying capacity by 37% by the end of three years, thus brush control radically increases the possible animal population that can be supported.

Millions of acre feet of water are being used each year by worthless brush.* By herbicide treatment of the undesirable plant species a very definite agriculturally favorable ecological change can be accomplished.

Several illustrations of the ecological aspects of herbicide control of chaparral brush are found in Pond's (1964) report. An "overstrong" kill releases "understory" vegetation. Thus, defoliation alone releases plant species found closer to the ground. In Pond's study the new understory growth was both grass and half shrubs; however, there was a different response after weed brush killing on quartzite soil than on a diabase soil. Both grass and half shrub forage plants increased on the quartzite soil but only half shrubs increased on herbicide treated diabase soil. The latter apparently does not support good grass growth. Not all herbicide effects are limited to weeds. Blaisdell et al. (1956) reports that 13 of 38 forbs were damaged during sagebrush spraying with 2,4-D in Idaho. Therefore, a range manager must be aware of this deleterious effect on the desirable plant species.

Occasionally chemical control of brush may create a more serious brush problem. Hyder et al. (1958) observed that selective killing of the sagebrush in mixed stands of sagebrush and green rabbit brush released the rabbit brush for more rapid increase and thereby created a serious problem. It is much more difficult to control the rabbit brush since it requires more herbicide and is susceptible only in favorable years. Thus weather and climate also aid in the release of a plant species.

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* Personal communication from C. E. Fisher.

The needs for herbicide control procedures are also affected by wildlife habits. Herbel points out that rabbits and rodents which live in the brush-infested areas, work out into adjacent grasslands depositing seeds and thereby accelerating brush invasion.

Quimby (1966) cautions that the conflict between sagebrush control programs and the welfare of wildlife cannot be ignored or denied. He presented data suggesting that antelope, sage grouse, deer, elk and moose might be adversely affected by 2,4-D spraying for brush. On the other hand, bighorn sheep are essentially not bothered by chemical brush control.

The introduction of an insect species, e.g., beetles, as mentioned under the biological methods of weed control, is a man-induced ecological change in the rangeland ecosystem which could have widespread and long-lasting effects (U. S. Department of Agriculture, 1966).

Man is part of the total ecosystem and cannot be overlooked in a discussion of ecologic effects of herbicide control methods. However, in the most part of the herbicide influence on man is indirect, yet the effect of man on the ecosystem is great since he decides upon and applies the principal control measures to rangeland.

It is obvious that no ecosystem is static and the extensive discussion of herbicide applications to rangeland bears out the fact that the vegetation land is constantly changing. The changes are both beneficial and detrimental and may be the result of man's activity or a natural ecologic change unrelated to man's activity.

IV. HERBICIDE APPLICATION ON WATERWAYS, PONDS, LAKES AND RESERVOIRS

Introduction

Aquatic vegetation growing in both lentic and lotic habitats (i.e., moving and static water in waterways, lakes, ponds, and reservoirs) serves useful as well as deleterious functions relative to the anthropocentrically oriented uses provided by these aquatic environments. Eradication of aquatic weeds has assumed progressively greater importance in recent years directly as a consequence of man's enormous increase in population and his widespread alteration of both the biotic and abiotic environments. Furthermore, advances in technology have introduced weed control requirements which were not necessary previously.

Among the items associated with aquatic weed control needs are: fire hazard, water pollution, mosquito control, irrigation and drainage ditching, outdoor recreation waterfowl and fish management, and even control of bird nesting grounds at the end of jet-aircraft runways (Steenis, 1966). Meyer (1964) has pointed out that aquatic plants are an important source of food for many organisms (e.g., muskrats, waterfowl, herbivorous fish, and insects) and that they form a food chain base as well as cover for fish and wild birds. However, these plants also interfere with the flow of water in drainage ditches, irrigation canals, and other waterways. In addition to more serious economic problems, they cause taste and odor problems and can even block access to the water areas by fishermen and boaters.

Removal of undesirable plants from aquatic areas thus has been, and will continue to be, important for man's optimum utilization of the aquatic environment. However, for this "optimum utilization," consideration of the effects of aquatic weed control cannot be limited solely to the immediate effects resulting from either the eradication methods used or the vegetation control itself, but consideration must also be given to the overall, long-term ecological effects of these programs. The effects of residual toxicity of any herbicides used to other plants and animals, the possible effects of the killed plants on other organisms, and many other factors must be considered in the light of their ecological effects. Since removal of aquatic weeds is bound to have some effect on the ecology of an area, it is important to try to ascertain that the gains achieved by weed control are not likely to be offset by losses due to undesirable ecological alterations.

Historical

Prior to the use of herbicides, hand and mechanical methods were used to remove aquatic weeds. These nonchemical methods were probably used on aquatic weeds as early as similar methods were used on terrestrial weeds. Herbicides in the modern sense have been used for aquatic weed control for over 60 years, although as long ago as the Middle Ages it was noted that certain arsenic and inorganic compounds possessed desirable herbicidal properties. Even earlier, salt was used as a primitive chemical method for killing plants (zur Burg et al., 1967). Two of the compounds used early in the 1900's, and which are still used today, are copper sulfate and sodium arsenite. Major uses of these compounds have been for the eradication of algae (copper sulfate) and water hyacinths and submerged weeds (sodium arsenite). Timmons (1963) has briefly reviewed the historical aspects of herbicide use in aquatic environments.

In the 1940's the use of other herbicidal materials was introduced for aquatic weed control, e.g., chlorinated benzenes, xylol-type benzenes, and 2,4-D. Relatively little interest in aquatic weed control was shown in Northeastern, North Central and Southern areas prior to 1955, or in the Western area prior to 1950, based on the low number of papers presented at regional Weed Control Conferences. A major interest in aquatic weed control began about 1957 when the Agricultural Research Service approximately tripled its research effort and contracted with Auburn University to evaluate 750 chemical compounds as aquatic herbicides. In 1958 Congress authorized the U.S. Army Corps of Engineers to spend $1,350,000 annually in eight Atlantic and Gulf Coast States for the control of aquatic weeds (Timmons, 1963). A review of the published literature since that time shows that interest in aquatic weed control has continued to grow in all parts of this country as well as throughout the rest of the world.

Dr. LeRoy Holm (1967) toured parts of West Asia, the Middle East and Africa while in the employ of the United Nations Food and Agriculture Organization in order to assist developing nations in the tropical regions of the world with weed control problems. He said that weeds pose a serious economic problem to these countries and that the White Nile water hyacinth infestation required the expenditure of $1.5 million annually by the Sudan Ministry of Agriculture just to keep the weed-choked river open to navigation. He added that they have perhaps the largest organization in the world combatting a single weed. They have a number of planes, land vehicles and boats; where they can't get vehicles in, they fly the men with knapsack sprayers into the area and let them walk out. At present, hostilities in the South prevent weed control treatments far enough upstream to do a good job; mats break off, float downstream and reinfest. Holm confirmed that native villages were cut off by weed-choked streams and had to move. The principal herbicide used in this particular weed control program is the 2,4-D amine salt (also see Kirkpatrick, 1958).

The weed control program in the Belgian Congo began in 1955 at which time about 940 miles of the Congo River was badly infested with water hyacinth. After two years of spraying from planes, boats and land vehicles and at a cost of 1 million dollars the river was cleared and the hyacinth problem was under control. Now that the Belgian government has pulled out, the river has been neglected and the river now is again in bad condition.

A program to irrigate 1.4 million acres of farm land in India is now in difficulty because of the growth of weeds in the irrigation canals and the estimated 80% reduction in the delivery of water. Crop losses have been high because of the inability to deliver the water where it is needed. In Nicarauga a water reservoir has become so clogged with water weeds that the production of power was threatened; aquatic weed control procedures involving herbicides are being used successfully to control the weeds there (Holm, 1967).

Aquatic weed problems are becoming more acute on the Zambesi River between Zambia and Rhodesia. The plant giving the trouble there is a water fern, Salvinia, and it has grown so fast on Lake Kariba that the lake surface is said to have exploded; the lake is man-made and has a surface area of 2,000 square miles; the weed now covers 200 square miles but is creating hazards by moving with the wind in large floating mats over the lake surface.

Aquatic weed problems occur in the cooler climates as well. The Marine Department, Rotorua, New Zealand (Fish, 1966) has conducted studies on the elimination of Lagarosiphon major from Lake Rotoiti. The aquatic herbicide diquat at 0.5 ppm controlled this weed well in one test arm of the lake but it was quickly replaced, first by large number of phytoplankton and photosynthetic algae and ciliates, then by an anchored alga, Nitella species.

Stovell (1960) discussed the progress in aquatic weed control in England and stated that the River Boards and other authorities were spending in 1960 850,000 pounds sterling per year on mechanical methods to control weeds that block navigation and the submerged weeds which impede the flow of water in drainage ditches. He added, however, that acrolein and a granular form of 2,4-D looked promising as a method to cut down on the labor requirements.

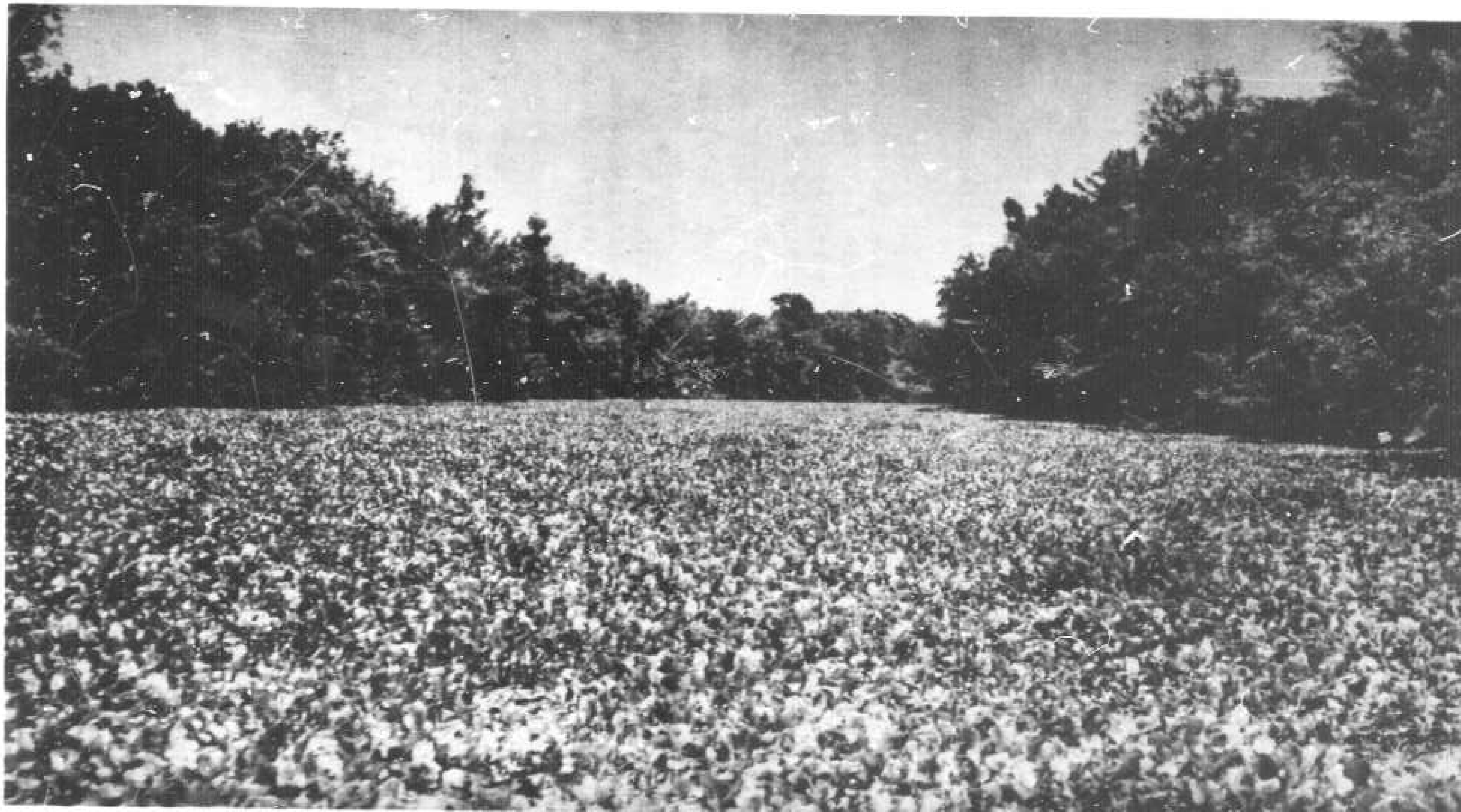
Current Use

A large number of species of aquatic plants require eradication from selected environments. The damage caused by some of these plants and their removal has been reviewed recently by Steenis (1966). For example, the upright emersed phragmites (Phragmites communis) is a highly adaptable plant which readily becomes dominant in disturbed environments such as marshes and fill areas near dredging sites. Fire hazard is caused by this dense grass along canals, oil storage sites, industrial locations, power and telephone lines (e.g., East River and Lower Hudson River in New York City) and elsewhere. This plant also dominates marshes, destroys wildlife habitats, and furnishes roosting places for blackbirds which are hazardous to jet planes during landing and takeoff. Steenis (1966) has described some control treatments effective against this plant:

"Habitat differences often alter control specifications. Phragmites were controlled in dry sites, when 2½ ft high to early fruiting, by amitrole-T at 12 lb. ai/A (active ingredient/acre), by dalapon at 30 lb. ae/A (acid equivalent/acre), and by the combination of amitrole-T at 2 lb. ai plus dalapon at 10 lb. ae/A. In wet but unflooded sites, the period for control was from full growth prior to tasseling to early fruiting (Beck and Steenis, 1964). Amitrole-T at 15 lb. ai/A, dalapon at 50 lb. ae/A, and the combination of Amitrole-T at 4 lb. ai plus dalapon at 20 lb ae/A were effective. In flooded habitats the period for control was during flowering to early fruiting. Amitrole-T at 15-20 lb. ai/A, and the combination of amitrole-T at 4 lb. ai plus dalapon at 20 lb. ae/A were effective; but, dalapon alone at any concentration was not (Steenis et al., 1959)."

Other examples of plants known to be troublesome are the water hyacinth (Eichhornis crassipes), alligatorweed (Alternanthera philoxeroides), spatterdock (various Nuphar species), lotus (Nelumbo lutea), duckweeds (Lemna minor, the common duckweed; Spirodella polyrhyza, giant duckweed), water chestnut (Trapa natans), sea lettuce (Ulva lactuca), water lettuce (Pistia stratiotes), filamentous algae (Zygnema, Spirogyra and Oedogonium), and Eurasian watermilfoil (Myriophyllum spicatum). These plants together with phragmites are among the aquatic weeds which cause serious difficulties in mankind's use of some aquatic environments.

The water hyacinth is an important southern weed which usually grows as a free-floating plant in fresh water and reproduces primarily by a vegetative root stalk method but also by seeds. Since they are free-floating, water hyacinths are readily dispersed in water. Their growth can be so extensive that they almost completely cover the water surface (Figure IV-1),



Courtesy U.S. Army Corps of Engineers

Figure IV-1 - A Typical Water Hyacinth Problem Area impede boat movement, and reduce oxygen levels in the water so that game fish cannot survive (Eggler, 1953). Water hyacinths as well as alligator weeds were introduced from South America (Steenis, 1966) and both plants were early recognized as potential weed problems. In 1902 the Corps of Engineers instituted a program for control of water hyacinths in Louisiana with the herbicide sodium arsenite. Later this group developed a number of mechanical devices to control the water hyacinth (zur Burg et al., 1967; Wunderlich, 1964).

In 1944 experiments conducted at the University of Southwestern Louisiana showed that almost any 2,4-D derivative would destroy the water hyacinth, and in 1945 experiments were begun there to determine effective dose levels of 2,4-D compounds for removing this aquatic weed. The effectiveness of 2,4-D derivatives in removing water hyacinths is very good: this plant is well controlled by application of 2-4 lb/acre of 2,4-D amine salt or its low-volatile esters. Diquat or amitrole-T is also effective and at levels of 1-1.5 lb/acre (Harrison et al., 1966). In spite of control efforts in the southern states on water hyacinth, as well as on alligator weed, these weeds have not yet been controlled. The effectiveness of 2,4-D compounds in removing water hyacinths was in fact later found to be followed by a massive increase in alligator weed, which apparently is inhibited by the water hyacinth umbrella (zur Burg et al., 1967). Thus in 1959 in 8 southeastern states it was estimated that water hyacinths and alligator weeds respectively infested 265,980 and 121,220 acres of aquatic environment. Estimates for 1963 indicated that infested acreage under control amounted to 161,554 for water hyacinth and 44,110 for alligator weed, and in untreated or uncontrolled areas the acreages were respectively 417,950 and 183,636 (House Document 251, 1965).

Alligator weed is a rooted emergent which grows best in shallow water over a mud bottom and thrives in the Gulf coastal area of the United States (e.g., in the delta and floodplain areas of the Mississippi River and in other rivers flowing into the Gulf of Mexico). It grows in fresh as well as in brackish water. Free-floating pieces do not grow well, but they remain alive and begin growing when they reach a proper area for rooting (Eggler, 1953). This weed has spread to other parts of the country, and thousands of acres are infested from Texas to Virginia. The plant is highly aggressive and adaptable, and its unobstructed growth blocks navigation channels, municipal water supplies and drainage and irrigation ditches. Because of its dense growth it provides optimum conditions for mosquito breeding, and few fish or other aquatic animals can live beneath its dense floating mats which create a low-oxygen environment. It competes with food and cover plants and is therefore harmful to the native wildlife. It can even invade canefields and reduce yields from sugar cane (McGilvrey and Steenis, 1965).

Alligator weed was first reported in the United States in 1897 (Harrison et al., 1966). It was pointed out as early as 1901 that alligator weed was a serious potential threat to water environments. The alligator weed is almost universally considered to be a weed of no economic value, although some cattlemen in southwestern Louisiana use it as a feed for cattle in winter (zur Burg et al., 1967). Alligator weed is not, however, limited in this country to the Gulf Coast area. For example, this weed was spread widely through the South Carolina low country by 1939. At this time in Lake Marion, which comprises 110,600 acres, 500 acres of alligator weed were found in widely scattered regions. In Lake Moultrie, which comprises 60,400 acres, the weed was sparsely distributed. Control measures were initiated in 1943, but these measures were ineffective. Use of 2,4-D was begun in 1947, but it was discontinued in 1950 since this herbicide was found to destroy only the aerial portion of the plant. Excellent control against rooted alligator weed was later achievable in water not over 18 inches deep with granular silvex at a rate of 20 lb. acid equivalent per acre. A primary problem in these South Carolina reservoir lakes nevertheless remains because of reinfestation from floating mats (Power and Walsh, 1965). In 1949 the lakes contained 20,000 acres of alligator weed, which was reduced to 7,000 acres in 1959 and to about 2,500 acres in the 1960's. During 1964 521 acres were treated (material costs averaged $35 per acre for granular 2,4-D and $75 per acre for granular silvex) (Power and Walsh, 1965).

Various herbicidal treatments, in addition to the ones described above, against alligator weed have been reported by Weldon and Blackburn (1965), Lawrence and Funderburk (1965), zur Burg et al. (1967) and others. Zur Burg et al. (1967) have concluded that the basic reason for the lack of control of alligator weed is due to the fact that its dormant buds are highly resistant to almost any chemical treatment.

Eurasian watermilfoil is a rooted perennial which can produce thick surface mats of vegetation (sometimes over 7 ft thick) which seriously interfere with the harvesting of fish, crabs and shellfish. Overgrowth with this plant also damages waterfowl habitats by crowding out duck food and other native plants, and it can seriously hurt recreational uses and real estate values of the affected areas. It can provide excellent breeding habitats for mosquitoes, a problem which is especially significant in areas such as the Tennessee Valley Authority reservoirs where malaria mosquitoes pose a serious problem. This milfoil has invaded fresh and brackish waters along the Atlantic coast and is becoming established in inland lentic habitats throughout the United States. "At present this plant is established in the Northeast in Massachusetts, Vermont, New York, Pennsylvania, New Jersey, and Delaware. In the Midwest it is reported in Ohio, Indiana, Illinois, and

Wisconsin. It is now invading lakes or estuarine areas in Maryland, Virginia, North Carolina, Georgia, Florida, Alabama, Louisiana, Texas, and also reported in California. New invasions in the Southeastern States have recently occurred at Lake Seminole, Georgia; Chassahowitzka Lake, Florida; Caddo Lake, Louisiana; and several interior ponds in Texas. Eurasian water milfoil also became more widely spread in other aquatic habitats in the States where it previously occurred." (Crowell et al., 1967).

Once this plant has invaded an area it can increase rapidly. For example, it has rapidly spread over 200,000 acres throughout the Chesapeake Bay area and its tributaries during approximately the past 10 years. Another example of Eurasian watermilfoil's impressive growth potential can be provided by citing its recent increase in the Currituck Sound region of North Carolina where in 1965 only 100 acres was classified as infestation stage and 500-1,000 acres as initial establishment of the plant. By the summer of 1966 approximately 8,000 acres was classified as heavily infested with milfoil and the plant was established in another 67,000 acres (there are about 98,000 acres of open water in Currituck Sound plus an additional 23,000 acres of connecting waters of Back Bay).

Noteworthy economic losses are incurred by overgrowth with Eurasian watermilfoil. In the Chesapeake Bay area, under proper management oystermen every three years can harvest oyster crops valued at $2,400 per acre. In the Currituck Sound-Back Bay area in recent years approximately 85,000 largemouth bass and 30,000 waterfowl have been harvested annually (and the majority of this harvest occurred in the areas most endangered by the watermilfoil). With overgrowh of watermilfoil this production is lost.

Herbicides have been successfully used for Eurasian watermilfoil reduction or removal beginning with early tests employing phenoxy formulations (Rawls, 1965). A 2,4-D treatment has been developed which is not harmful to food-chain organisms or to commercial fish growing in the Chesapeake Bay area. Also, oysters and clams are not adversely affected by this treatment of milfoil, and analytical studies have shown that these shellfish tend to cleanse themselves of 2,4-D residues (Steenis, 1966). Experiments of Lowe cited by Rawls (1966) on oysters exposed to 2,4-D BE* a concentration of 0.1 ppm in flowing sea water for 7 days showed that the oysters accumulated an average of 18 ppm of this herbicide, but after "flushing" for 7 days no 2,4-D BE residue could be found in their tissues. Thus even if oysters required as long as several months to free themselves of residual herbicide, treatment of the oyster beds during the vulnerable milfoil period would find the oysters essentially free of residue by the September harvest period.

* Butyl ester of 2,4-D.

For control of Eurasian watermilfoil available evidence indicates that 2,4-D is the herbicide of choice. Time and habitat are factors which influence the application of this compound:

"Differences in habitat also determine specifications for control of Eurasian watermilfoil. A standard procedure for control of this plant is dispersal of 2,4-D ester on attaclay granules at the rate of 20 lb. ae/A. In tidal waters and reservoirs, best results have occurred with butoxyethanol ester of 2,4-D because the balance of residual and release of this formulation seems best adapted in these situations. However, in lakes other 2,4-D esters have been equally effective." (Steenis, 1966) Crowell et al. (1967) have indicated that the nonvolatile esters of 2,4-D impregnated in attaclay particles applied at 20 lb. acid equivalent per acre is a satisfactory level for selective and safe control of this plant and results in a release of growth of desirable native plants such as southern naiad, wildcelery, redhead grass, sago pondweed, and widgeongrass which serve as waterfowl food.

The water chestnut is another aquatic weed that can effectively prevent use of water areas by man and destroy animal wildlife habitats. This plant is of Asian origin and was introduced into New York in about 1884, presumably to decorate a pond. In 1900 it was a common decorative plant on the Washington Mall. The water chestnut is an annual aquatic plant which forms a dense cover of overlapping leafy rosettes. Each rosette can produce 15-20 hard, thorn-covered seeds, each approximately the size of a hickory nut. The seeds are buoyant and can be transported by water currents. Moreover, they remain viable for several years and therefore complicate control operations (Rawls, 1964; Steenis and Stotts, 1966; Steenis and Elser, 1967).

Water chestnut infestations occur primarily in New York and Maryland. In New York these plants are mainly in the Hudson-Mohawk Valley area where it is well established (as well as more vigorous and more resistant to control than in Maryland). In Maryland infestations occurred in the upper Chesapeake Bay area. Although this plant does not infest saline water, there is a large area of fresh water in the upper Bay which can be invaded. (Steenis and Elser, 1967). By 1923 water chestnuts were found in Oxon Run opposite Alexandria and 10 years later 10,000 acres were occupied by this plant in the Potomac (Rawls, 1964).

Removal of water chestnuts from the Potomac area was instituted because these plants were seriously interfering with navigation. The U.S. Army Corps of Engineers successfully utilized underwater mowing techniques for its removal, and during recent years water chestnuts have seldom been seen in the Potomac. Water chestnut control in this area can be achieved with only hand removal (Rawls, 1964).

In the New York area good progress has been made in controlling water chestnuts with 2,4-D, although this compound has not been uniformly successful. 2,4-D was applied with variable success in the fresh and slightly brackish waters of the upper Chesapeake Bay. Extensive cutting and pulling operations are also conducted in the Bay area (Steenis and Stotts, 1966); Steenis and Elser, 1967). Apparently 2,4-D has been used successfully for controlling blanket growths of water chestnut where there is little or no water movement. However, preliminary tests showed that combinations of 2,4-D (at 4 lb. acid equivalent per acre) with other chemicals such as dicamba (at 2 lb. acid equivalent per acre) gave better control in tidal areas (Steenis and Stotts, 1966).

Water lettuce (Pistia stratiotes) is a floating water plant which develops an extensive root systems (18 to 36 inches long); the plants interlock to form thick masses of vegetation which are strong enough to stop a boat, interfere with fishing and lower the dissolved oxygen in the water below them. It is a problem primarily in areas that remain warm all year. Cold weather, not necessarily freezing, will kill it. Mats of water lettuce serve as breeding grounds for a number of species of disease carrying insects including those insect vectors for encephalomyelitis and rural filariasis (Provost 1949; and cited by Weldon and Blackburn, 1967).

A number of herbicide formulations have been examined to determine a satisfactory control procedure. In a study at Fort Lauderdale, Florida, atrazine at 20 lb. per acre gave 80% control, 2,4-D PGBE* ester at 8 lb. per acre gave 76% control and diquat at 1.5 lb. per acre gave 97% kill (Weldon and Blackburn, 1967).

An extensive literature on other weeds exists. For example: duckweeds (Blackburn and Weldon, 1965a); cattail (Timmons et al., 1963); elodea (Blackburn et al., 1966); coontail and southern naiad (White, 1963); etc.

Methods of Aquatic Weed Control with Herbicides

The need for aquatic weed control has been discussed earlier. The question considered here is, what are the best, cheapest and quickest methods to control these vast expanses of aquatic weeds? Unfortunately there is not any simple answer which will apply to all kinds of weeds under all situations. Based on the knowledge that mechanical injury to water hyacinth plants killed them, boats were constructed which would pick up the hyacinth from the water,

* Propylene glycol butyl ether ester of 2,4-D.

put it through rollers and put it back into the water. This method killed the hyacinth as planned but it served to spread other aquatic weeds (King, 1966). The introduction of 2,4-D in its various formulations and some of the newer herbicides have enabled men to control more weeds with less manpower than any other method currently available. The subjects to be discussed in this section include: (1) problems in the use of herbicides for effective aquatic plant control, (2) selection of chemicals for the control of specific aquatic weeds and (3) the future of biological weed control methods alone or in combination with herbicides.

The use of herbicides for the control of aquatic weeds poses some unique problems due in part to differences in plant morphology and in part to the differences in the plant environment. When trees, brush and other terrestrial weeds are sprayed with herbicide, relatively large quantities of the herbicide-spray actually contact the foliage, stem and in some cases the roots (i.e., following precipitation). A similar direct application of herbicide spray to the exposed portion of aquatic vegetation is possible and for some weeds this is enough since the translocation process carries the herbicide throughout the plant. On the other hand for the submersed weeds and for the parts of the other weeds under the surface of the water the physical problem of carrying the herbicide directly to the plant without great dilution in a large mass of water is much greater than for the land weeds. Another problem is caused by differences in the plants themselves; a number of aquatic weeds such as the water hyacinth, pond lily, etc., are covered with a waxy coat which is only slightly permeable to aqueous solutions. Some of the other weeds such as elodea are highly permeable and nearly anything soluble in water can get into the plant. In selecting a herbicide, a formulation and an application method, one should consider all these factors in order to optimize the opportunity for the herbicide to be absorbed by the plant.

The application methods most used for the control of aquatic and ditchbank weeds involve the spraying of a herbicide (1) as an aqueous solution, (2) a nonaqueous solution (e.g., fuel oil solution of a 2,4-D ester), (3) the spraying of an invert emulsion (i.e., a water in oil emulsion which inverts when placed in large quantities of water) (Weldon, et al., 1966). An alternative method of dissemination often used consists of the broadcast distribution of a granular formulation (such as 2,4-D compound on attaclay granules). The latter are used particularly as a means of getting release of the herbicide close to the roots in the mud or silt bottom.

In the selection of a particular chemical for the control of an aquatic weed the easiest place to start is with a chart such as that given in Table IV-1. In this chart the weeds are arranged by types and the recommended herbicide and the rate of application are given together with a few precautions which should aid in preventing unnecessary damage to the fish or other biota.

TABLE IV-1

SUGGESTED CONTROL MEA[illegible]S FOR COMMON AQUATIC WEEDS OF FLORIDA

Weed	Status[a/]	Herbicide[b/]	Rate of Application[c/]	Remarks[d/]
ALGAE				
Plankton: (*Microcystis*, *Anabaena*, and *Aphanizomenon*)	R	Copper sulfate	0.25 ppmw	Soft water
	R	do.	1.00 ppmw	Hard water
Filamentous: (*Spirogyra*, *Oedogonium*, *Hydrodictyon*, *Pithophora*, and *Cladophora*)	R	Copper sulfate	0.5-1.0 ppmw	Soft water
	R	do.	1.0-2.0 ppmw	Hard water
	R	Endothall (amine salt)	0.25-1.0 ppmw	TOXIC to fish
	S	Sodium arsenite	4 ppmw	CAUTION: TOXIC to mammals Follow label directions
Higher algae: (*Chara* and *Nitella*)	R	Copper sulfate	1-2 ppmw	Soft water
	R	do.	2-3 ppmw	Hard water
	S	Sodium arsenite	4 ppmw	CAUTION: TOXIC to mammals Follow label directions
	S	Dichlobenil (granular)	6-10 lb/A	Broadcast over weeds
SUBMERSED WEEDS				
bladderwort (*Utricularia* spp.)	R	diquat	0.25-0.5 ppmw	Inject or apply on surface of nonflowing water.
			1-2.5 ppmw	Inject or apply on surface of slow-flowing water. Do NOT apply diquat to muddy water.
	R	acrolein	4-7 ppmv	Inject underwater; toxic to fish.
	R	endothall (amine salt)	1-2 ppmw	Inject in nonflowing water; toxic to fish.
			2-4 ppmw	Inject in slow-flowing water; toxic to fish.
	R	aromatic solvents	20-80 ppmv	Inject underwater; toxic to fish.
	R	sodium arsenite	4 ppmw	CAUTION: Toxic to mammals. Inject in ponds or lakes.
coontail (*Ceratophyllum demersum* L.)	R	Same as for bladderwort		
	S	endothall (disodium or dipotassium)	2-4 ppmw	Inject in ponds or small lakes.
eelgrass (*Vallisneria* spp.)	R	endothall (amine salt)	1.5 ppmw	Inject ponds or small lakes; toxic to fish.
	S	Dichlobenil (granular)	10-20 lb/A	Broadcast over weed area.
elodea (*Elodea canadensis* Michx., *Elodea densa* (Planch.) Caspary)	R	acrolein	4-7 ppmv	Inject underwater; toxic to fish.
	R	endothall (amine salt)	2-4 ppmw	Inject underwater; toxic to fish.
	R	aromatic solvents	20-80 ppmv	Inject underwater; toxic to fish.
	S	sodium arsenite	4 ppmw	Inject in ponds or lakes. CAUTION: Toxic to mammals.
	S	diquat	1-2 ppmw	Inject or apply on surface of nonflowing water. Do NOT apply diquat to muddy water.
naiad, southern (*Najas guadalupensis* (Spreng.) Magnus)	R	Same as for bladderwort		
pondweed (*Potamogeton* spp.)	R	Same as for bladderwort		

TABLE IV-1 (Continued)

Weed	Status[a]	Herbicide[b]	Rate of Application[c]	Remarks[d]
SUBMERSED WEEDS (Concluded)				
widgeongrass (Ruppia maritima L.)	R	diquat	0.5-1.5 ppmw	Inject or apply on surface of non-flowing water. Do NOT apply diquat to muddy water.
FLOATING WEEDS				
duckweed (Spirodela polyrhiza (L.) Schleid; Lemna minor L.; Wolffia spp.)	R	diquat	0.25-1 ppmw	Foliar spray or inject in non-flowing water. Do NOT apply diquat to muddy water.
salvinia (Salvinia rotundifolia Willd.)	R	diquat	1-2 lb/A	Spray on foliage.
water hyacinth (Eichhornia crassipes (Mart.) Solms.)	R	2,4-D (amine salt)	2-4 lb/A	Spray on foliage.
	R	2,4-D (low-volatile esters)	2-4 lb/A	Spray on foliage using water or fuel oil.
	R	diquat	1-1.5 lb/A	Spray on foliage.
	R	amitrole-T	1-1.5 lb/A	Spray on foliage.
	S	2,4-D (oil-soluble amines)	2-4 lb/A	Spray on foliage.
water lettuce (Pistia stratiotes L.)	R	diquat	1-1.5 lb/A	Spray on foliage.
frogbit (Limnobium spongia)	R	2,4-D	4 lb/A	Spray on foliage.
	R	diquat	1 lb/A	Spray on foliage.
EMERSED WEEDS				
alligatorweed (Alternanthera philoxeroides (Mart.) Griseb.)	R	silvex (low-volatile esters)	8 lb/A	Spray on foliage. Repeat application when regrowth is 4-6 in. above water surface.
	R	silvex (granular)	20-30 lb/A	Use only on rooted alligatorweed growing in 6-8 in. of water. Broadcast over weed surface.
arrowhead (Sagittaria spp.)	S	2,4-D (low-volatile esters)	4-8 lb/A	Spray on foliage using water or fuel oil.
	S	silvex (low-volatile esters)	4-8 lb/A	Spray on foliage using water or fuel oil.
bulrush (Scirpus spp.)	S	2,4-D (low-volatile esters)	4-8 lb/A	Spray on foliage using water or fuel oil.
cattail (Typha spp.)	R	dalapon	15-20 lb/A	Spray on foliage.
	R	dalapon plus diesel oil (emulsifiable)	5-10 lb/A 10 gpa	Spray on foliage.
	S	amitrole-T	4-6 lb/A	Spray on foliage. Two applications 1 month apart.
parrotfeather (Myriophyllum brasiliense Camb.)	S	2,4-D (low-volatile esters)	4-8 lb/A	Spray on foliage.
	S	2,4-D (granular)	20 lb/A	Broadcast over weed surface.
	S	Silvex (granular)	1-2 ppmw	Inject ponds or small lakes.
pennywort, water (Hydrocotyle spp.)	S	2,4-D (amine salt)	2-6 lb/A	Spray on foliage using 0.1% v/v surfactant.
	S	diquat	1.5 lb/A	Spray on foliage.

TABLE IV-1 (Continued)

Weed	Status[a]	Herbicide[b]	Rate of Application[c]	Remarks[d]
EMERSED WEEDS (Concluded)				
pickerelweed (*Pontederia cordata* L.)	S	silvex (low-volatile esters)	4-8 lb/A	Spray on foliage.
	S	silvex (granular)	20 lb/A	Broadcast over weed surface.
primrosewillow (*Jussiaea* spp.)	R	2,4-D (amine salt)	2-6 lb/A	Spray on foliage.
rush (*Juncus* spp.)	S	silvex (low-volatile esters)	4-8 lb/A	Spray on foliage using water or fuel oil.
	S	2,4-D (amine or emulsifiable acid)	6-8 lb/A	Spray on foliage.
sawgrass (*Cladium jamaicense* Crantz)	R			Underwater mowing.
	S	dalapon plus diesel oil (emulsifiable)	10-20 lb/A plus 20 gpa	Spray on foliage.
smartweed (*Polygonum* spp.)	S	2,4-D (low-volatile esters)	4-8 lb/A	Spray on foliage using water or fuel oil.
spatterdock (*Nuphar advena* (Ait.) Ait. f.)	S	2,4-D (granular)	30-40 lb/A	Broadcast over weed surface.
	S	silvex (low-volatile esters)	2-4 ppmw	Inject ponds or small lakes.
	S	silvex plus endothall (1:1 ratio)	2-4 ppmw	Inject ponds or small lakes.
waterlily (*Nymphaea* spp.)	S	Same as for spatterdock.		
	S	2,4-D (low-volatile esters)	4-6 lb/A	Spray on foliage using water or fuel oil. Repeat frequently.
watershield (*Brasena schreberi*)	S	Same as for spatterdock		Same as for spatterdock.
AQUATIC AND DITCHBANK GRASSES				
cutgrass, southern (*Leersia hexandra* Sw.)	S	dalapon	5-20 lb/A	Spray on foliage. Repeat applications.
knotgrass (*Paspalum distichum* L.)	R	Bromacil	20-40 lb/A	For muck; 1/2 rate for mineral soils.
	R	Diuron	20-40 lb/A	For muck; 1/2 rate for mineral soils. (Both R are soil sterilants)
	S	Dalapon	5-10 lb/A	Spray on foliage using 0.1% v/v surfacants. Repeat applications.
maidencane (*Panicum hemitomon* Schult.)	R	Same as for knotgrass		
	R	dalapon	15 lb/A	Spray on foliage. Repeat applications.
paragrass (*Panicum purpurascens* Raddi)	R	Same as for knotgrass		
	R	dalapon	5-10 lb/A	Spray on foliage. Repeat applications 2-3 weeks apart.
reed, common (*Phragmites communis* Trin.)	S	dalapon	20 lb/A	Spray foliage at preflowering stage.

TABLE IV-1 (Concluded)

Weed	Status[a/]	Herbicide[b/]	Rate of Application[c/]	Remarks[d/]
AQUATIC AND DITCHBANK GRASSES (Concluded)				
torpedograss (*Panicum repens* L.)	S	dalapon	15-20 lb/A	Spray on foliage. Repeat applications 2-3 weeks apart.
water paspalum (*Paspalum fluitans* (Ell.) Kunth)	S	dalapon	5-10 lb/A	Spray on foliage using 0.1% v/v surfactant. Repeat applications.
watergrass, southern (*Hydrochloa carolinensis* Beauv.)	S			Underwater mowing.
DITCHBANK BRUSH AND TREES*				
castorbean (*Ricinus communis* L.)	R	2,4,5-T	4 lb/A	Spray plants when small or treat resprouts from stumps.
guava, common (*Psidium guajava* Raddi L.)	R	2,4,5-T	4 lb/A	Spray entire plant or resprouted stumps.
	R	fenuron	20 lb/A	Very toxic to all plants.
pepper tree, Brazilian (*Schinus terebinthifolius* Raddi L.)	R	2,4,5-T	Same as for common guava.	
	R	2,4,5-T (ester form)	16 lb/100 gal oil.	Cut down tree and paint stump.
pine, Australian (*Casuarina equisetifolia* Forst.)	R	2,4-D or 2,4,5-T	16 lb/100 gal oil	Use as a frill or stump treatment.
seamyrtle (*Baccharis halimifolia* L.)	R	fenuron	20 lb/A	Very toxic to all plants.

* For mixed ditchbanks, grasses, brush and small trees:

	R	Amitrole-T	2-5 lb/A	Split applications

CAUTION: Do not contaminate water when applying herbicides to bank weeds and brush.

a/ Status: R - Recommended for satisfactory control.
S - Suggested for possible or partial control.

b/ Herbicides referred to by common name, see Herbicide Handbook, Weed Society of America, 1967.

c/ Abbreviations used: ppmw = parts per million by weight; ppmv = parts per million by volume; lb/A = pounds per acre; and gpa = gallons per acre.

d/ Where foliar application is recommended, mix herbicide in 150 gpa water unless otherwise specified.

Source: D. S. Harrison, R. D. Blackburn, L. W. Weldon, J. R. Orsenigo and G. F. Ryan, Aquatic Weed Control. University of Florida Agricultural Extension Service Circular 219B, August 1966, 16 pp.

The reader is also referred to the USDA Agriculture Handbook No. 332 (1967) which follows a similar format but lists some additional treatments for aquatic weed control. A much more comprehensive listing of weeds and the herbicides which control them has been compiled by Lawrence (1962 and 1966). Listings of chemicals and the weeds they control has been assembled by Blackburn (1966a) and also by DeVaney (1967).

McClure (1965) points out that it is not enough to match the herbicide and its formulation to the weed being killed. The intended use of the water must also be considered; for example, a 2,4-D compound should not be used in an irrigation ditch if the water is going to irrigate a 2,4-D sensitive crop such as cotton, etc. (Bruns and Yeo, 1964).

A number of other chemicals which are being used in the control of aquatic and ditchbank weeds and which have been omitted from this table are listed here:

Atrazine	2-Chloro-4-ethylamino-6-isopropylamino-s-triazine
Dicamba	2-Methoxy-3,6-dichlorobenzoic acid
Dichlone	2,3-Dichloro-1,4-naphthoquinone
DSMA	Disodium methanearsonic acid
Fenac acetamide	2,3,6-Trichlorophenylacetamide
Fenac sodium	2,3,6-Trichlorophenylacetate, sodium
MCPA	2-Methyl-4-chlorophenoxyacetic acid
MSMA	Monosodium methanearsonic acid
Paraquat	1,1'-Dimethyl-4,4'-bipyridinium salt
Picloram	4-Amino-3,5,6-trichloropicolinic acid

Since new compounds are being developed and old compounds are being formulated for use on aquatic weeds this listing will not be complete.

The word "control" is used frequently in describing aquatic weed management. It usually means that the numbers of weeds have been greatly reduced or that the area of open water has been enlarged. Seldom does it mean that the noxious weed is completely eliminated or that some other noxious weed will not become dominant. Therefore, repeated applications of herbicides at appropriate intervals, depending upon the circumstances, will be required for the majority of treated areas.

In the future it would be highly desirable if aquatic plants could be used for some beneficial purpose rather than destroyed. Several approaches to this problem have been considered. Lange (1965) reports that a project is being conducted at Caddo Lake in cooperation with Texas A and M which involves the harvesting and drying of the aquatic weeds and feeding them to cattle, swine and poultry. Results show that 13 tons of the weeds are required to produce one ton of dried meal. Because of its high xanthophyll content this meal may be useful as a component in broiler feed. Another approach would use the Nile tilapia (Tilapia nilotica), and the Congo Tilapia (Tilapia melanopleura), two herbivorous fish, for the control of aquatic vegetation (Pierce and Yawn, 1965). In experiments conducted in Atlanta, Georgia, it was found that the Tilapia did a fine job in cleaning ponds of the branched alga Pithophora. Two difficulties were encountered: when the water temperature fell to 50°F the fish died and secondly the Tilapia apparently did not reproduce if there are bass present in the lake. Sguros (1965) describes an experiment using the Florida Manatee for weed control. In their experiment one male and three female Manatee ranging in weight from 350 to 2,000 lb. and up to 12 ft in length were adapted to fresh water. They consumed large quantities of southern naiad, bladderwort, cattails and spike rushes but waterlily types such as spatterdock and arrowhead were assiduously avoided. They made a half mile of weed-choked canal navigable in a week. Other methods of biological control are being investigated and these include use of snails (Blackburn and Weldon, 1965), and plant eating insects (Hawkes, 1965). and many others. For the foreseeable future herbicides will continue to be the method of choice for most aquatic weed control. Insects for the control of alligatorweed may be an exception.

Economics of Aquatic Weed Control

An accurate assessment of the economic losses due to aquatic vegetation is not available even for this country, although the costs must be very high since, for example, in Louisiana alone from 1946-1950 the loss from aquatic weeds was about $35 million per year(zur Burg et al., 1967). Apart from estimated losses due to aquatic weeds, it has been estimated that about $5,500,000 is spent annually for treating lakes and ponds in the U.S., and this amount of money was for treatment of only approximately 10% of the weed infested areas. Moreover, in 17 western states in 1957, 63,448 miles of canals were treated for aquatic weeds which represented 54% of the aquatic weed infested area (Timmons, 1963). Table IV-2 taken from Timmons' paper (1963) shows the total lake acreage treated with herbicides for control of weeds.

Large sums of money are spent in other countries also. For example, the Sudan government spends $1.5 million annually to reduce the quantity of water hyacinths which choke the White Nile. Some years ago, the Belgian government spent $1 million to clean approximately 1,000 miles of the Congo River of this same aquatic plant. Further examples of aquatic weed problems are furnished by Nicaragua, India and other countries (Holm, 1967).

TABLE IV-2

TOTAL ACREAGES IN LAKES TREATED WITH CHEMICALS FOR CONTROL OF AQUATIC WEEDS, 1961 SURVEY

Kind of Weed	Acres Treated*	No. of States Reporting
Filamentous algae	10,552	14
Nonfilamentous algae	33,808	10
Rooted submersed	15,373	16
Rooted emersed	10,576	16
Floating	39,611	10

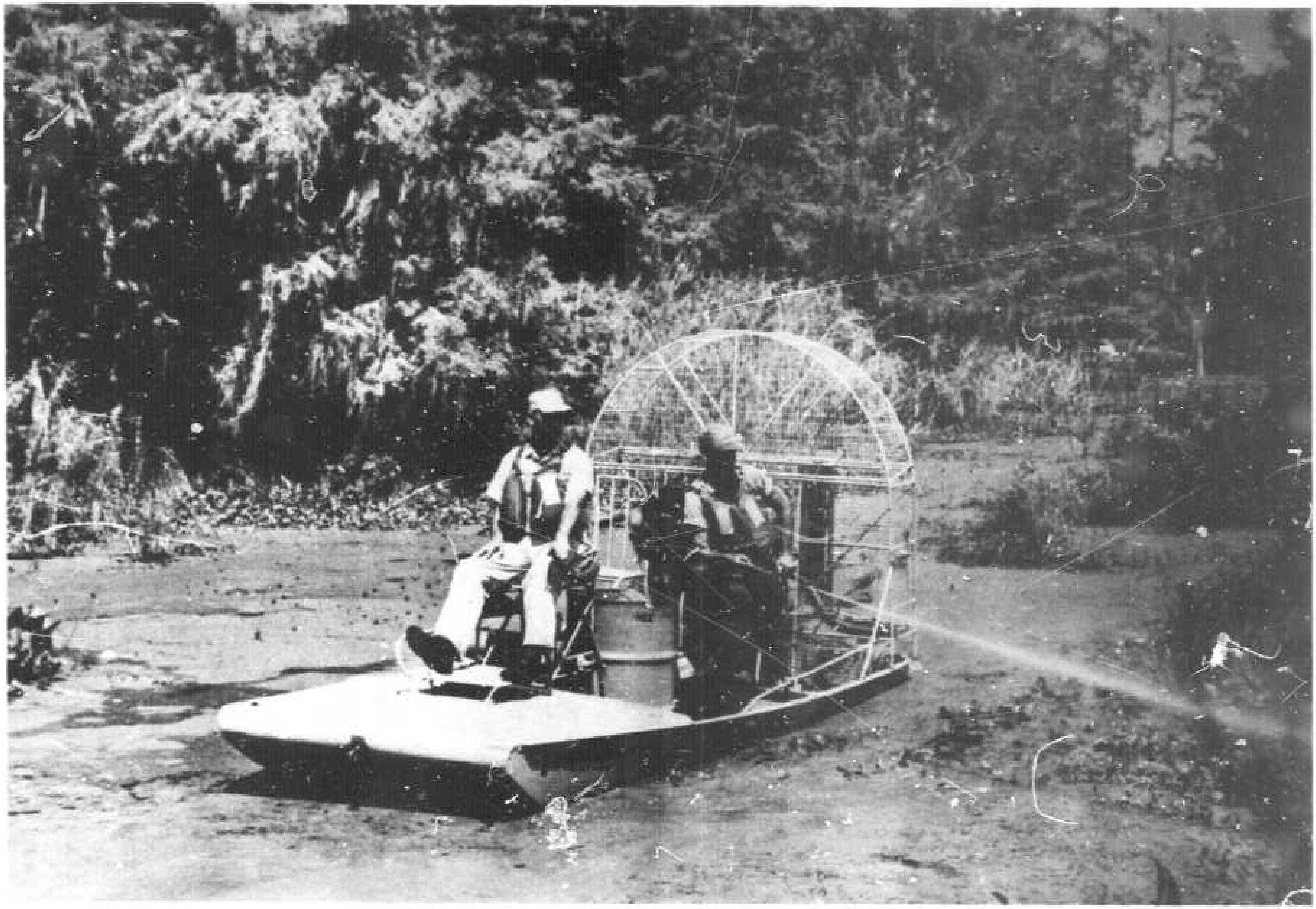
Rather elaborate calculations of the annual benefits of the Expanded Project for Aquatic Plant Control (House Document 251) in the states of Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina and Texas have been compiled:

Flood and control and drainage (urban)	$ 580,000
Water and flood control (agriculture)	3,590,000
Fish and wildlife	3,310,000
Recreation	3,600,000
Mosquito control	170,000
Water supply	100,000
Pollution control	2,610,000
Total Annual Benefits	$13,960,000

In addition to these estimated benefits which appeared to be very conservative attention is called to the fact that if there had been no control program the area of infestation would have grown from 387,200 acres in 1959 to 601,590 acres in 1963. The cost for treating 187,660 acres amounted to $187,600 or an average cost of $21.45 per acre. Figures IV-2 and IV-3 show some equipment and some results of this program conducted by the U. S. Army Corps of Engineers.

A drainage engineer has estimated the hand labor costs on clearing a certain ditch at $3,000 per mile, with the trimming out of regrowth a year later at $900 per mile. Chemical control in the same ditch costs $700 per mile the first year and the second spraying a year later costs only $300 (Abramson, 1965).

* Does not include Western States.



Courtesy U.S. Army Corps of Engineers

Figure IV-2 - Airboat with Mounted Spray Equipment

Courtesy U.S. Army Corps of Engineers

Figure IV-3 - Typical Hyacinth Infestation Before Treatment (above) and Seven Months After Treatment (below).

Montgomery (1965) reports that the Bureau of Sports Fisheries and Wildlife spent $20 an acre for the control of aquatic weeds in the waters of the southeastern National Fish Hatcheries during the calender year of 1963. This treatment improved the habitat for the fish and the fishing for the sportsmen.

Ecological Consequences of Aquatic Weed Control

A toxicological study on the effects of 2,4-D (BEE)* impregnated attaclay pellets was carried out in experimental one-acre tidewater plots in Potomac tributaries in the Chesapeake Bay area (Beaven et al., 1962). For this study caged oysters, crabs, clams and fish were held near the center and outside of plots of Eurasian watermilfoil (Myriophyllium spicatum L.) during and after treatment with the 2,4-D preparation. They found that when normal aerobic conditions were maintained, 30 lb. acid equivalent per acre, neither caused mortality to the fauna nor killed the native plants. These authors point out, however, that a series threat to bottom organisms can occur when large mats of decomposing milfoil remain on the bottom.

In another study in the Chesapeake Bay area on the toxicity to caged estuarine animals of herbicides used to control Eurasian watermilfoil of the compounds tested only 2,4-D acetamide appeared to be dangerously toxic to test animals at levels needed for milfoil control. (Rawls, 1965). Blue crabs (Callinectes sapidus), eastern oysters (Crassostrea virginica), softshell clams (Niya arenaria) and various species of fish were studied using principally 2,4-D formulations (PGBEE, BE, IOE, and acetamide 2,4-D compounds and silvex were among the agents tested). The field tests were run over a number of years (1960-1963). All the caged animals died in the milfoil plot where 2,4-D acetamide was applied at 20 lb. acid equivalent per acre. Rawls (1965) has briefly reviewed the toxicity literature dealing with the effects of herbicides on estuarine animals. (See also Pierce, 1959, and Yeo, 1967.)

Probably the greatest effect that herbicides have on a fresh-water ecosystem is the destruction of the weeds. This is particularly important to man and wildlife since aquatic weeds endanger human health and reduce food supplies. Wet weed mats are the natural breeding places for insects which carry human and animal diseases (e.g., bilharziasis, malaria). Heavy mats of floating weeds shut out the light so necessary for the oxygenation of the water and the survival of fish. In many areas, river communities depend heavily on the fish for a source of protein to balance their grain diet (Holm, 1967).

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* Butoxyethyl ester of 2,4-D.

Water lettuce, alligatorweed, water hyacinth, and other weed species are a serious problem in the southern United States and other tropical areas when they choke irrigation canals and cut off the water supply to the farms supplying man's food needs. These same plants may cause flooding of farm lands and the formation of mats which may push over bridges in time of floods; they may also block ships so they cannot enter the channels. Such things as bridges and boats are important in maintaining man's food chain.

Many observers have noted that when a weed covering the surface of a body of water is destroyed, there is a sequence of events occurring which leads to a replacement of the destroyed vegetation--often with another weed. In the case of water hyacinth removal, alligatorweed often moves in to replace it. Experience shows that this or similar plant succession occurs after either chemical or mechanical weed removal of weeds.

The consequences of not using herbicides for aquatic weed control may be as serious to man and some wildlife as any consequences from using them. Water weeds have not always been a problem and their removal helps to restore the fresh water aquatic environment to its original or natural state.

If herbicides can prevent the spreading of aquatic plants to larger areas without producing other direct toxic effects, they will be helping to preserve fresh-water ecosystems rather than destroying them. We are of the opinion that the consequences to ourselves and to wildlife habitat will be greater if we do not control the aquatic weeds than if we do. Herbicides properly used can do an effective job of weed control; biological weed control measures may be increasingly important in the future but for the present man will probably continue to use the weed control method which does the necessary job at the lowest cost.

V. MILITARY APPLICATIONS OF HERBICIDES

Unlike civilian applications of herbicides in forestry, range management, and aquatic weed control, the development and use of herbicides for military purposes have not been adequately documented in the scientific literature. Although many post-war military herbicide investigations have been unclassified, the military technology relating to defoliants, desiccants and chemical agents for crop destruction has received little attention in the chemical, botanical, and ecological journals.

Within the past few years, a general concern has been expressed by the scientific community regarding the use of vegetation-control chemicals by the military. Therefore, in order to provide a better basis for considering the ecological consequences of various military uses of herbicides, these applications must be described in somewhat greater detail than are the civilian uses.

Information has been drawn entirely from publicly available reports, the unclassified technical literature and news accounts. The following sections represent a factual account of the background and development of military herbicides, the policies controlling the use of herbicides, and the materials and application procedures currently used in Vietnam. A brief description of the vegetation in Southeast Asia is presented along with its response to herbicidal treatment. The possible ecological consequences of these operations will be discussed separately.

Background and Historical Development of Military Herbicides

Throughout World War II, classified military research on chemical herbicides played an important role in the development of the potent selective herbicides now in world-wide use. In the search for chemical agents to destroy enemy crops, many of the key concepts of herbicidal mechanism and species selectivity were elucidated, and the effectiveness of the phenoxy herbicides as weed control agents was first demonstrated.

In late 1941, a group of prominent scientists convinced the Secretary of War, Henry Stimson, of the potential dangers from biological warfare. Stimson requested the National Academy of Sciences and the National Research Council to provide the best possible scientific advice. In response, the National Academy of Sciences established the "ABC" Committee; and, in February 1942, the committee's report resulted in the establishment of the War Research Service, a civilian agency with George Merck as the director.

Although a number of plant physiologists and other scientists had carried on a decade of research with plant hormones and synthetic growth-regulating agents, and many workers had noted that overdoses of plant hormones or growth regulators injure plant tissue or even kill the plants, no one had yet suggested that hormone-like agents might be useful as herbicides. Several of these research workers were destined to play pivotal roles in the development of both military herbicides and modern weed killers.*

These scientists included Dr. E. J. Kraus, Head of the Botany Department of the University of Chicago, who had worked extensively with growth regulators and plant hormones, and two of his doctoral students, John Mitchell and Charles Hamner, who since 1940 had both been working as plant physiologists at the USDA Plant Industry Station, Beltsville, Maryland.

Apparently, Kraus was the first to suggest that growth regulators might work as herbicides if purposefully applied to weeds in toxic doses (Peterson, 1967a). Early in 1941 he discussed this with Mitchell and Hamner, later elaborating his ideas in letters to them (Marth and Mitchell, 1944; Mitchell, 1966). Within a few months, Kraus and Mitchell began work testing various synthetic growth regulators for their herbicidal activity. In April 1942, Kraus and Mitchell learned about the work soon to be published by Zimmerman and Hitchcock (1942) of the Boyce-Thompson Institute. Zimmerman had found that the phenoxyacetic acids are exceedingly powerful growth regulators, and that one of the most potent for inducing seedless tomatoes was 2,4-dichlorophenoxyacetic acid, which was 300 times more powerful than the widely used indolebutyric acid. Without indicating the intended use, Mitchell obtained some of these chemicals, including 2,4-D, from Zimmerman and began testing a variety of compounds as herbicides in the greenhouses at the University of Chicago and Beltsville.

Kraus was sufficiently encouraged by the early results that, in late 1942, he suggested to the committees of the National Academy of Sciences that "the toxic properties of growth-regulating substances for the destruction of crops or the limitation of crop production" might be of military interest, and proposed that the herbicidal properties of these growth-regulating chemicals should be tested on field crops (Kraus and Mitchell, 1947). Because of the war, Kraus and Mitchell did not publicize the results of their 1941-1943 experiments.

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* A thorough historical review of wartime research on herbicides, recently prepared by the Smithsonian Institution, has been published in Agricultural History, July 1967 (Peterson, 1967b). Mitchell's original 1-lb. bottle of 2,4-D is now a part of the collection in the Smithsonian's Division of Agriculture and Forest Products.

The United States Army initiated a contract with the University of Chicago in March 1943 to support the research of Kraus and Mitchell, and to pay for much of the work which had already been done. Since the war against the Japanese in the Pacific was of increasing importance, it is not surprising that the effectiveness of 2,4-D and 2,4,5-T in killing rice was included in these investigations (Kraus and Mitchell, 1947). Although the early results were promising, it was later learned that rice is generally quite resistant to 2,4-D.

Largely on the basis of the results Kraus had reported to the National Academy of Sciences, the Army intensified its herbicide research, assigning this mission to the recently established Camp Detrick (Peterson, 1967c). The Army research team carried out the synthesis and testing of nearly 1,100 substances in laboratory screening, greenhouse tests, and later under the direction of Mitchell, as applied to field crops.

Until the end of the war, the U.S. research program was an official secret. However, on January 3, 1946, Secretary of War, Robert Patterson, made public a letter from George Merck which listed, among other significant accomplishments of the wartime program, the testing of "the effects of more than 1,000 different chemical agents on living plants." Although victory was achieved before the herbicides could be used in wartime operations, Merck declared that "only the rapid ending of the war prevented field trials in an active theatre of synthetic agents that would, without injury to human or animal life, affect the growing crops and make them useless."(Merck, 1946, and Shalett, 1946)

Even though the war-time research effort was directed primarily toward anticrop agents, the investigators could foresee the considerable possibilities that 2,4-D had in agriculture. The plant industry research group at Beltsville procured 1 lb. of pure 2,4-D from the American Chemical Paint Company, and began testing 2,4-D for the control of various common weeds. These trials also included toxicity studies and animal feeding tests which established the safety of 2,4-D. To clinch this point, Kraus personally consumed 1/2 g/day for three weeks with absolutely no effect (Cohen, 1948) and (Proc., NCWCC, 1945).

During the summer of 1944, results came rapidly from a number of research groups: the selective action of 2,4-D was reported (Mitchell and Hamner, 1944); the report by Hamner and Tukey (1944) of successful control of bindweed attracted considerable public attention; and this public interest in weed killers persuaded several chemical companies to produce and market 2,4-D commercially. The following year, 1945, saw the introduction of "Weedone," the first systemic herbicide.

Defoliants for Jungle Warfare

Nearly 20 years of research and testing were devoted to the attainment of defoliation systems capable of stripping away jungle foliage.

The record of technical development dates back to the establishment of Fort Detrick in the winter of 1942-1943. The war in the South Pacific was making new demands on military technology:

> "There was a great deal of interest at that time in destroying vegetation in the South Pacific theatre, and the principal means available was high explosives. I have forgotten how many millions of tons of high explosives were required to destroy the vegetation on some of these Pacific islands. We were asked to investigate chemicals that were available in large quantities in the United States that could be employed for 'defoliating' this vegetation." (Minarik, 1963a).

The tactical uses of chemical defoliants in counter-insurgent operations have been summarized:

> "The capability of destroying cover and concealment to defend against and fight off guerrilla and other types of tactics is absolutely essential. When we clear vegetation from roadsides, railways, and canals, we substantially reduce the opportunity for ambush, and thus allow our own operations to proceed in a more timely manner. Defoliants would also be used to demarcate boundaries. Defoliation could be used to clear gun emplacements, open up fields of fire, mark areas of bombing, or test whether or not a particular area was camouflage or actual vegetation."(Delmore, 1963)

Near the close of the war, aerial spraying of several inorganic defoliants was tested against sub-tropical vegetation in the Florida Everglades. These tests demonstrated that spray droplets applied to the forest canopy penetrated, not only the top leaves, but also the middle stratum, and some even reached the forest floor (Minarik, 1963b). Therefore, multiple treatment is not essential in stripping away tropical cover.

By June 1945, the Army was prepared to recommend the use of ammonium thiocyanate as a defoliant in the Pacific theatre. However, high Government levels decided that:

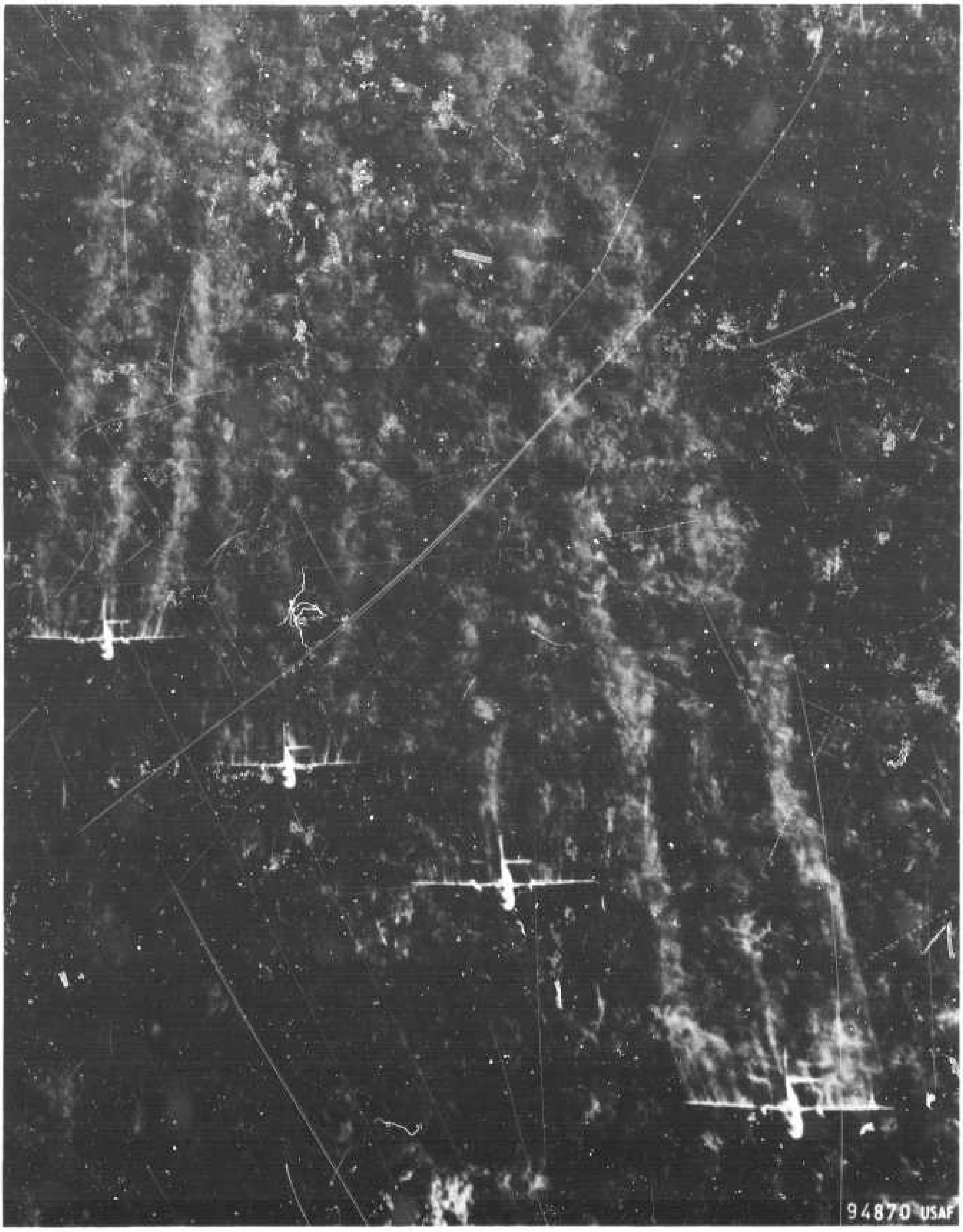

Figure V-1 - U. S. Air Force C-123 Spray Planes Defoliating Dense Forest Cover in South Vietnam

"Ammonium thiocyanate sounded very much like cyanide, which everybody knows is poisonous. If we used this chemical, we would be accused of conducting poison-gas warfare; therefore, the plan to use chemicals for destroying vegetation in the Pacific theatre was dropped. The war ended before another 'defoliant' could be developed." (Minarik, 1963a)

The chemicals used at this time are more accurately termed desiccants--agents which injure foliage by direct chemical action on contact, causing the leaves to turn brown, curl, dry up, and wither. Leaf drop by abscission may or may not occur. Since there is little absorption or translocation, only the foliage and green stems are destroyed and the rest of the plant may recover. The effect is like a heavy frost. Such agents are often termed "contact herbicides."

In a post-war program, Fort Detrick examined approximately 12,000 chemicals for defoliant and desiccant activity. The most promising 700 chemicals were screened in greenhouse and field tests for their defoliant activity (Minarik 1963b and Preston et al., 1959). Some of these defoliants were subsequently tested against tropical vegetation in Puerto Rico (Brun et al., 1961).

A highly significant demonstration of vegetation control was conducted at Camp Drum, New York, 1959. Using a mixture of undiluted butyl esters of 2,4-D and 2,4,5-T applied at 0.75 gal/acre, the trees were denuded over an area of 4 square miles (Brown, 1959).

Shortly after this successful defoliation test, the government of South Vietnam requested the U. S. Army to undertake trials of defoliants for use against guerrilla forces. This request coincided with the first announcement in the U.S. that--

"The army is experimenting with chemical techniques for stripping jungle areas of foliage to expose guerrilla fighters or other hostile forces and installations. . . .that chemical agents had already been perfected that would strip wooded areas of their foliage in about two or three days." (Raymond, 1961).

A variety of chemical agents were shipped to the Vietnamese military authorities, and from July 1961 to April 1962, a preliminary series of defoliation trials were conducted under the guidance of J. W. Brown. Even though wartime conditions interfered with the collection of detailed data, these tests established that the esters of 2,4-D and 2,4,5-T were active in killing a majority of the species encountered in Vietnam, providing the herbicide spray was properly applied to the vegetation during a period of active growth. In addition, the first aerial application of cacodylic acid showed promise as a fast-acting desiccant (Brown, 1962).

It was recommended that further screening of chemicals and development of application systems be conducted in Thailand or other tropical areas having vegetation similar to that in Vietnam.

The defoliation results were sufficiently encouraging that President Diem's government in Saigon announced on January 1, 1962, plans to use new techniques in a strong counter-offensive against communist guerrilla forces, stating:

> "Numerous techniques hitherto unseen in South Vietnam's jungle warfare are being inaugurated or are about to be used to help turn the tide of battle against the Viet Cong. One of these techniques is 'defoliation' from the air; a chemical means of stripping leaves from the foliage that hides Viet Cong movements in thickly wooded areas. Known Viet Cong bases will be surrounded by bare stretches where the guerrillas will find it difficult to move undetected from their hideouts, which are often underground." (Turnbull, 1962)

Further screening of herbicides and development of application systems have been conducted in areas of Thailand having vegetation similar to that in Vietnam. Fort Detrick directed the OCONUS defoliation test program in Thailand, utilizing test sites approved by the Thai government and military authorities (Darrow, 1966a).

Concurrently, the Department of Agriculture conducted related defoliant studies for the U. S. Army at test sites in Texas and Puerto Rico (Tschirley, 1967a).

Vietnamese military forces conducted several large-scale tests in the spring of 1962. United States planes sprayed jungle growth along Highway 15, connecting the U. S. Air Force Base at Bien Hoa just outside Saigon to the seacoast city of Cap Saint Jacques. This 70-mile route had been considered unsafe for months, and government officials had to travel by air. Following this test, a high Vietnamese official said:

> "Defoliant chemicals would also be sprayed on Viet Cong plantations of manioc and sweet potatoes in the highlands. The exact locations of these plantations have already been plotted by aerial surveys. Tests have shown that manioc and sweet potatoes die four days after having been sprayed. These are the two most important food staples for the communist bands in the mountains." (Bigart, 1962)

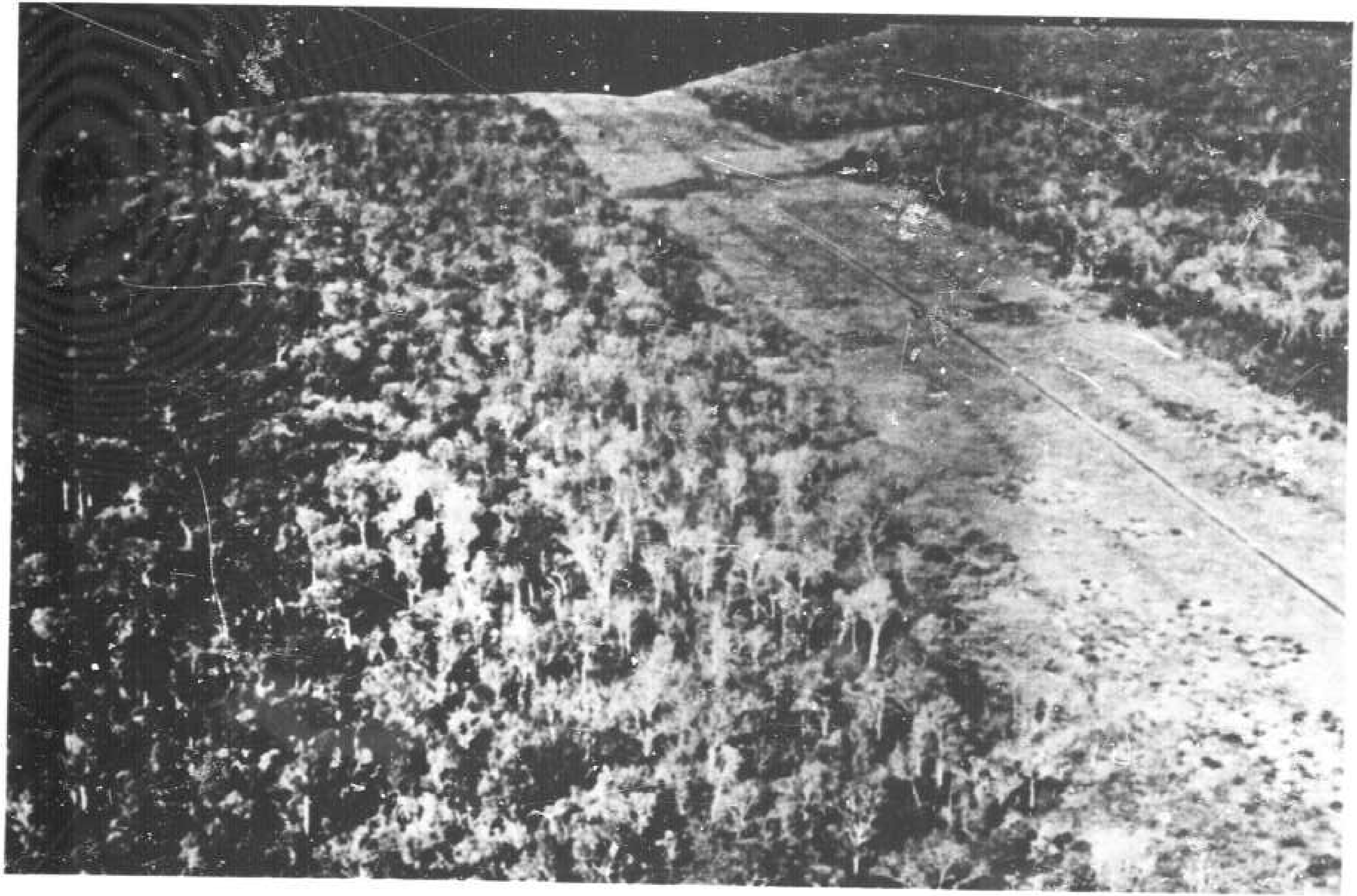

Figure V-2 - Roadside near Chon Thank, 76 to 80 Kilometers North of Saigon. Sprayed 24 August 1961. Photo taken 16 November 1961 shows partial defoliation 300 ft back into an upland forest varying from relatively dense to open. (Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Additional defoliation tests against mangrove and nipa palm vegetation along the canals and roads of the Ca Mau Peninsula were conducted in August 1962. In these trials the heavy delta vegetation was sprayed 400 meters back from the edge of the rivers and the roads over a total length of 79 km. The herbicide formulation known as "Purple" (a brush control formulation comprising butyl esters of 2,4-D and 2,4,5-T) was applied at rates of 1.5 and 3.0 gal/acre. The mangrove vegetation responded rapidly, and was completely defoliated in about one week. Nipa palm responded slowly, turning yellow and losing its leaves; it took five weeks for these palms to fall to the ground.

Defoliation after five weeks was rated, 95% leaf drop; while the visibility of the ground from directly overhead was increased by 90% (Armed Forces Chemical Journal, 1964a, and Minarik and Bertram, 1962a).

A second important aspect of the consequences of defoliation was shown in the Ca Mau tests. Following defoliation, the mangrove stands along some of the roads became accessible to the native woodcutters, who cut the trees, converted it to charcoal and sold it for fuel (Minarik and Bertram, 1962b). Where the land was suitable after removal of the trees, various crops have been planted and cultivated (Armed Forces Chemical Journal, 1964b).

Twenty years after Kraus had first suggested them to the National Academy of Sciences, the phenoxy herbicides became a tool of war. On November 21 and 23, 1962, the Vietnamese Air Force carried out the first operational spraying of herbicides for crop destruction in known Viet Cong strongholds (Peterson, 1967d).

Current Herbicide Use in Vietnam

Since 1961, when herbicides were first used in Vietnam (Raymond, 1965, and Mohr, 1965). military defoliation has become the largest known use of herbicides. The gradually changing role of the U. S. in the Vietnam conflict has, in turn, altered both the extent and the nature of herbicide applications.

Operation Ranch Hand

Defoliation missions of the U.S. Air Force were assigned to the newly created Special Spray Flight of the 309th Aerial Commando Squadron. When the first group of huge C-123 cargo planes, specially equipped for spray application, came to Tan Son Nhut Airport on November 29, 1961, the operation, destined to be known as "Ranch Hand," began to practice a new military technology (Pruden, 1966).

Courtesy Lewellyn Williams

Figure V-3 - Mangrove Swamp Woodland, Showing Uniformity of Canopy and Density of Stand

Aerial spraying of herbicides for defoliation or crop destruction cannot be directly compared with any of the civilian uses of herbicides. Even forestry spraying to suppress deciduous trees, thereby releasing conifers, represents a poor analogy. Military use of herbicides differs from other applications in several important respects--in objectives, herbicide formulations, dosage rates, and application methods; and the effects are influenced by the climate, vegetation and soils found throughout Southeast Asia. Therefore, some of the technical details of military use will be presented. These factors need to be considered before assessing the possibility of long-term ecological consequences.

Herbicide Formulations

Three basic types of herbicides are employed. The most widely used is the familiar brush killer mixture of 2,4-D and 2,4,5-T.

The chemical normally used for jungle defoliation is agent "Orange,"* a 50-50 mixture of normal butyl esters of 2,4-D and 2,4,5-T. Orange is the general purpose herbicide designed to kill foliage, with leaf fall in three to six weeks, and control persisting for seven to 12 months.

Prior to the adoption of "Orange," a closely similar interim agent known as "Purple" was employed. This formulation was a proprietary, commercial brush killer which differed from "Orange" in containing 20 percent isobutyl ester of 2,4,5-T. Experience has shown that "Purple" and "Orange" are equivalent in defoliation effectiveness, and can be used interchangeably.

Agent "White" combines picloram with 2,4-D in a low volatility amine salt formulation. This combination provides relatively longer duration control of a wide spectrum of woody plants, plus the advantages of accurate spray placement where volatility creates problems. This agent is closely similar to compositions used for aerial spraying of power line rights-of-way throughout the U. S.

Desiccant agent, "Blue," cacodylic acid is a contact herbicide employed for rapid defoliation. This formulation does not kill many woody species, but it is an effective grass control agent, particularly useful in keeping down heavy grassy vegetation along roadsides and surrounding military encampments.

For ease of comparison, details of each composition are summarized in Table V-1.

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* The herbicides derive their colorful names from the color-coded paint stripe which girdles each shipping drum.

TABLE V-1

COMPOSITION AND CHARACTERISTICS OF MILITARY HERBICIDES

Agent	Composition		Lb/Gal AE	Purpose
Orange	n-Butyl ester 2,4-D	50% (wt)	4.2	General defoliation
	n-Butyl ester 2,4,5-T	50% (wt)	3.7	Forest
		Total	8.9	Brush
				Broad-leafed crops
Purple	n-Butyl ester 2,4-D	50% (wt)	4.2	General defoliation
	n-Butyl ester 2,4,5-T	30% (wt)	2.2	Interim agent used
	Isobutyl ester 2,4,5-T	20% (wt)	1.5	Interchangably with Orange
		Total	8.9	
White (Tordon 101)	Tri-isopropanolamine salt 2,4-D		2.0	Forest defoliation
	Tri-isopropanolamine salt picloram		0.54	Long-term jungle control
		Total	2.54	Brush suppression
Blue (Phytar 560-G)	Sodium cacodylate	27.7%		Rapid defoliation (short duration)
	Free cacodylic acid	4.8%		
	Water; sodium chloride	bal.	3.1	Grassy plant control
				Rice destruction

Herbicidal action of the "Orange" and "White" formulations depends upon absorption by the plant tissue and translocation throughout the plants. Properly applied, in sufficient doses, this systemic effect can kill plants, and prevent root sprouting in all but the largest and most resistant trees.

Cacodylic acid or "Blue" does not depend upon translocation or systemic action. This organic arsenical compound (dimethylarsenic acid) acts much like the closely related arsenical crabgrass killer MSMA (monosodium methane arsonate) used on lawns. Both compounds are highly effective killers of certain grass plants. Cacodylic acid was originally intended for the control of Imperata, elephant grass, bamboo and other plants of the grass family in defoliation operations (Beecher, 1966). However, the early defoliation trials in Vietnam showed that cacodylic acid was a fast-acting contact desiccant capable of withering vegetation within a few days (Brown, 1962b). When applied to foliage in high concentrations, cacodylic acid destroys the leaf before appreciable translocation can take place. When applied at lower rates, absorption and translocation throughout the plant are possible. It is used on rice fields in enemy controlled country, where it destroys existing crops but does not affect subsequent growths (Lucas, 1967).

In most civilian applications of herbicides, the weed killers are diluted in oil or water as a carrier, or are emulsified as normal or as invert emulsions. For military applications, however, the "Orange" and "Purple" agents are sprayed undiluted. Many years of experience in aerial application of herbicides in the U. S. have shown that the ester formulations generally achieve better control of the treated vegetation than can be obtained with amine salts and other formulations.

Application Factors

The spray equipment used in Vietnam, as well as the application parameters, are significantly different from what is used in other herbicide spraying operations.

Both fixed-wing and helicopter applications have been made. The HU-1B helicopter has been made available to the U.S. Army and to the Vietnamese Air Force (R.V.N.A.F.) for special types of herbicide applications.

The basic spray plane, however, is the twin engine C-123 aircraft, equipped with a chemical tank of 1,000-gal capacity and A/A45y-1 internal defoliation dispensers (Farm Chemicals, 1966a). Each plane is fitted with two wing booms and a tail boom, using 14 nozzles on each wing boom and eight on the tail boom. All spray operations are controlled from a console located in the back of the plane, designed to insure uniform flow and accurate rates of spray application. The normal crew complement consists of pilot, co-pilot,

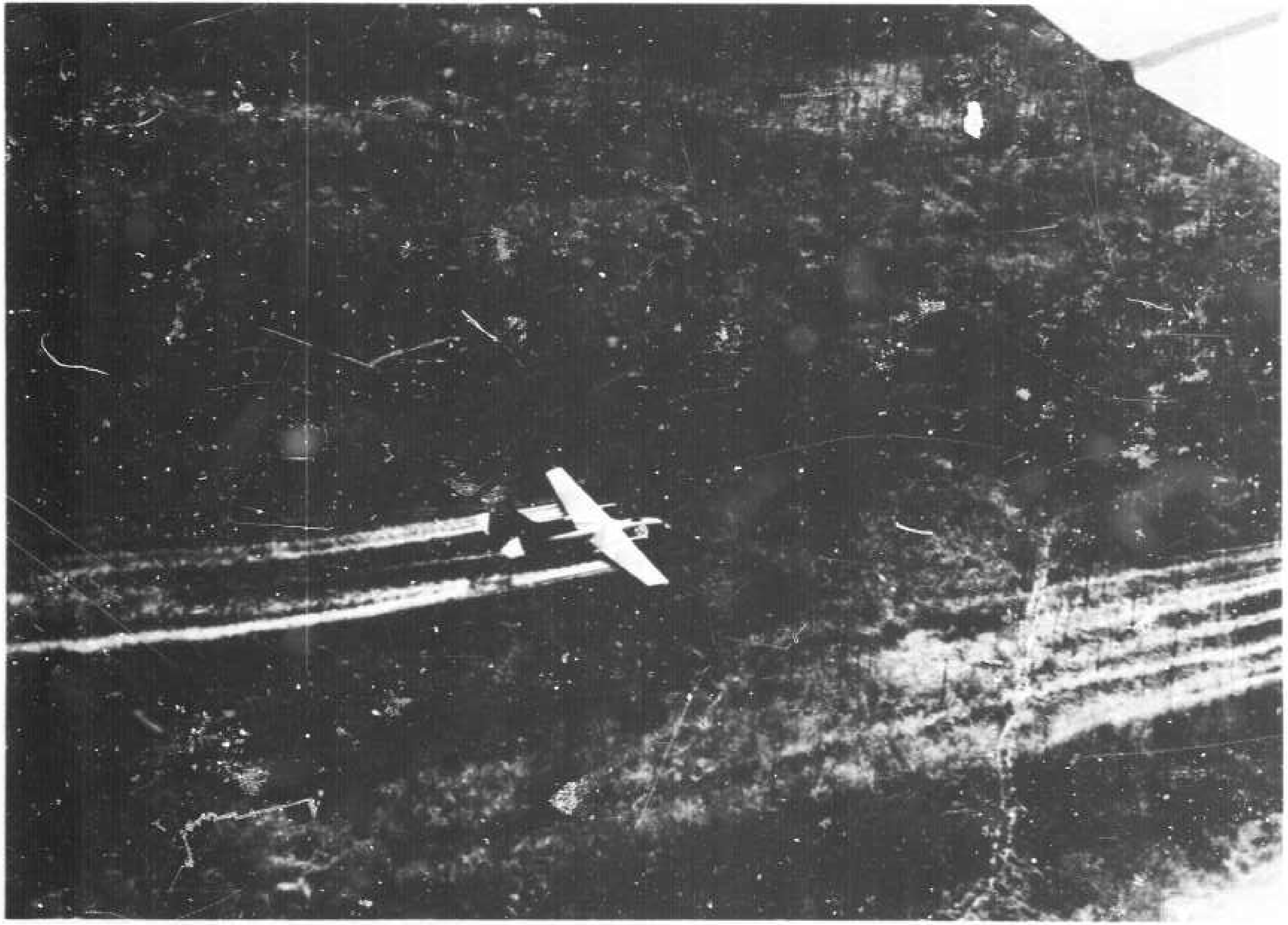


Figure V-4 - Ranch Hand Planes at Tree-Top Height Clear Strips through Viet Cong Strongholds to Disclose Ground Activity. Low level application in still morning air helps minimize drift and provides maximum reduction in obscuration. (Courtesy U.S. Army Biological Laboratories, Ft. Detrick) and a technical specialist who operates the spray console. The spray equipment is calibrated to discharge the 1,000-gal tank in a 5-min period; however, the tank can be emptied in 30 sec in case of emergency.

Like aerial spraying for civilian applications, the spray run is made as close to the foliage as practical, and at a relatively low speed. The forests of Vietnam have a canopy which generally reaches up to 90 ft, with occasional trees towering to about 125 ft. The normal altitude for spray application is 150 ft. Speed is maintained at 130 knots, only 7 knots above stall speed (Lucas, 1967). Under these conditions, the spray emerging from the open nozzles is atomized by air turbulence to produce herbicide droplets ranging from 100 to 400 μ in diameter with an average drop size of about 300 μ. The spray mist settles onto the forest canopy in a swath approximately 250 ft wide.

Weather, wind and thermal currents greatly influence the effectiveness of the herbicidal spray. The most effective spray results are obtained in the early morning when the wind is calm and the spray can settle directly onto the target (Lucas, 1967).

Tests have been made to determine the degree of spray-droplet interception by the canopy, and by the intermediate and lower stories in the forest (Tschirley, 1967b). In a moist tropical forest, approximately 80% of the spray droplets are intercepted by the foliage of the topmost canopy; 14% caught by the intermediate levels of vegetation; and only 6% of the total spray application reaches the ground level plants. Data on penetration achieved with several different types of spray booms is contained in the Appendix, Figure A-2 (p.300).

Spray drift is an important factor which influences the effectiveness of herbicide applications. Many fine droplets (200 μ or less) are formed when liquid is released from aircraft. These small drops are markedly affected by air currents. For example, a 200 μ droplet will drift 9 ft while falling 20 ft in a lateral airflow of 1 mph. (Tschirley et al., 1967). The farther above the jungle canopy the spray is released, the more drift will occur.

Some drifting of small droplets occurs under almost all conditions. Calibration tests conducted in Thialand established that it is necessary to release about 20% more herbicide than will be deposited onto the jungle vegetation. For example, a specified treatment with 100% "Purple" at 2.0 gal/acre deposit volume required release of 2.5 gal/acre from the aircraft, giving a recovery of 80% (Darrow et al., 1960). The 20% not deposited on the test cards used in calibration can be ascribed to a combination of drift and evaporation.

Air turbulence resulting from low flying aircraft is an important factor in providing distribution of spray throughout the vegetative profile.

When all droplets are falling in a straight line, most of them will be intercepted by the upper portions of the forest canopy. Turbulence from the aircraft helps to distribute the droplets throughout the foliage. The number of drops deposited per square inch of leaf surface has a striking effect on the response of herbicides. Behrens (1957) found that the effectiveness of 2,4,5-T increased greatly as the number of droplets per square inch increased from nine to 72, while the total amount of 2,4,5-T remained constant.

The picloram and cacodylic acid formulations are considered non-volatile, and thus are subject only to wind drift of fine droplets. The n-butyl esters of 2,4-D and 2,4,5-T, on the other hand, exhibit appreciable volatility under both laboratory and field conditions (King, 1966, Adams et al., 1964, Vernetti and Freed, 1964, and Miller, at al., 1954). Specialists point out that even so-called low volatile esters of the chlorophenoxy acids will exhibit measurable volatility when sprayed at the temperatures prevailing in Vietnam. Thus it seems clear that herbicide vapors are formed when "Orange" or "Purple" are sprayed. In fact some of the effectiveness of these formulations in penetrating and defoliating heavy jungle vegetation has been ascribed in part to the vapors (Farm Chemicals, 1966).

Drift damage is usually minimized by allowing a suitable buffer zone. However, accidents have occurred. There are reports of sensitive vegetation, such as rubber trees or cotton, being damaged nearly 15 miles from the point of spray release (Pace, 1966).

Defoliation Targets and Objectives

Military considerations dictate how and where herbicides will be applied--factors greatly influencing the severity and permanence of ecological disturbance. The particular tactical objectives largely determine the type of vegetation treated, as well as whether temporary leaf drop or plant kill is obtained. Policies regarding target selection influence the geographic distribution of where the spraying is done, and the extent of the area covered by herbicide application.

The rate and nature of revegetation and succession largely depend on whether isolated strips and patches of jungle vegetation are destroyed, or whether large contiguous areas are controlled. Spraying cropland gives different ecological effects from those created by the defoliation of relatively undisturbed forest.

Aerial defoliation is carried on against vegetation which includes water weeds in the Mekong Delta, the multi-storied tropical rain forests, second-growth brush and grasses along communication routes, and mixed deciduous or semi-evergreen forests in mountain regions. Depending on the military objectives sought, herbicides are selected to produce short-term defoliation or long-term plant kill. The following list enumerates some of the major defoliation targets.

* Nipa palm and mangrove woodlands grow in coastal areas in deltas and within reach of tidal waters along the banks and out into the rivers and canals of South Vietnam. The edges of these waterways are sprayed for a distance of 200 to 800 meters back from the water (Minarik and Bertram, 1962c). Since these are permanent traffic routes, the objectives include total plant kill and long-term vegetation control. Respraying at yearly intervals is generally required.

* Rain or Moist Evergreen forests usually have three stories of foliage with a ground cover of shrubs, vines, and herbs of variable density. These targets are sprayed to create bare stretches surrounding Viet Cong strongholds so that movement of men or supplies in and out of the area can be observed from the air (Trumbull, 1962). This type of target requires rapid defoliation; however, long-term control or permanent kill is not essential.

* The dense shrubbery and second-growth brush along highways and supply roads create cover for ambush. These areas are defoliated back into the edge of the forest to deprive the Viet Cong of concealment (New York Times, March 10, 1966, Raymond, 1965, and Pruden, 1966). At points where Viet Cong are known to have set up road blocks for the confiscation of "taxes," an area 400 meters in extent is cleared to expose such operations for aerial reconnaissance and attack.

* In the Mekong Delta area, the Viet Cong often secrete caches of ammunition, food and supplies, so well concealed that they are difficult to find on the ground and impossible to detect from the air. Trees, weeds and underbrush are defoliated to disclose the location of these supply dumps.

* In areas that have been cleared for villages, buildings and military posts, heavy grasses and foliage may hide the infiltration of unseen attackers. This foliage is treated to hold down the grasses and foliage out to a safe distance. Long-term control is desirable in this application.

* Upland forests comprise mixed deciduous and semi-evergreen stands representing some of the heaviest forest canopies in Vietnam. Pathways and trails are defoliated between villages of the primitive mountain people and nearby Civil Guard defense units (Bigart, 1962). The same type of forest is typically found along the infiltration routes and supply trails just south of the Demilitarized Zone (New York Times, September 24 and 27, 1966). These areas are stripped to disclose troop and supply movements to aerial reconnaissance.

* A continuing struggle has been made to keep the National Rail Lines operating in spite of the fact that guerrilla bands have cut the line at numerous points by the demolition of bridges (Pruden, 1966). To minimize the opportunity for sabotage, the edges of the forest are treated at sufficiently frequent intervals to control foliage that would obscure guerrilla activity from the air.

* The mountain forests of the Annamite Chain hide the paths of supply trails from North Vietnam, through Cambodia and Laos into South Vietnam. Strategic points along both the Sihanouk and the Ho Chi Minh trails in Laos have been liberally sprayed (Foisie, 1966, and New York Times, May 19, 1966), presumably with the knowledge and cooperation of the Laotian Government (New York Times, May 19, 1966).

* The most recent and massive defoliation effort is now under way in the southern portion of the Demilitarized Zone (Bloomington Daily Herald, October 2, 1966, and New York Times, September 27, 1966) which contains some of the most dense forest vegetation in all Vietnam (Lucas, 1967). The DMZ, a 6-mile-wide zone extending 55 miles from the Gulf of Tonkin to the mountainous inland border has been sprayed for the last few months with hundreds of tons of herbicide (Washington Daily News, February 6, 1967). The lower 4 miles of the DMZ is scheduled for herbicidal treatment as well as mechanical removal where necessary (New York Times, September 23 and October 2, 1966).

* South Vietnamese crops have been destroyed with herbicides to deny food to the guerrillas (New York Times, March 10, 1966). Relatively few details about crop destruction missions are available. Crops said to have been damaged since spraying first began in 1962 (Pace, 1966, and New York Times, January 12, 1962), include: Manioc and sweet potatoes (Bigart, 1962), rice, sugar cane and vegetables (Pruden, 1966).

The selection and scheduling of targets for jungle defoliation or for crop-destruction missions involve a complex chain of military decisions and political review designed to achieve maximum effectiveness, as well as minimize the risk of unfortunate errors in herbicide spraying. These procedures have been described by Wesley Pruden, Jr. (1966).

"Setting up targets is a ticklish diplomatic business. Nominations are made by either U.S. or Vietnamese army commanders, but if an American officer wants a target sprayed, he has to pass the recommendation on to a Vietnamese officer, who goes over the target with the province chief. Then the recommendation goes to the Vietnamese army's general staff in Saigon and, if approved, the request is sent on to the intelligence section of the U.S. Military Assistance Command - Vietnam, in Saigon."

Finally, if it clears all these desks, the request goes to the U.S. Ambassador in Saigon. Occasionally, an especially ticklish request goes all the way to Washington. One recent example involved General Westmoreland's request to begin defoliation of the DMZ, which was submitted to Washington for approval (New York Times, October 2, 1966).

In spite of all precautions, occasionally some spray may drift from a target area, causing damage to rice crops or rubber trees. When claims are made, prompt action is taken to pay damages. The current price for a mature rubber tree is $87 (Beecher, 1966).

Even more stringent procedures are used to limit crop-destruction missions to those specific areas where military effect will be greatest. Charles Mohr (December 1965) reported:

"There is a complex system of political and military controls on the crop-destruction program. The program which began last spring has touched only a small fraction--50,000 to 75,000 acres--of the more than 8 million acres of cultivated land in South Vietnam. This is the intention of policy-makers.

"Although the Viet Cong control or at least contest 70% of the land area of the nation, crop-destruction missions are aimed only at relatively small areas of major military importance, where the guerrillas grow their own food or where the population is willingly committed to their cause.

"Officials say that no herbicide missions have been flown or will be flown in heavily populated areas. There has been no crop destruction, for example, in the Mekong Delta.

"There is concern that any attempt to destroy crops in heavily populated areas dominated by the Viet Cong could only send a new flood of displaced Vietnamese to join South Vietnam's 730,000 refugees.

"It is also suggested that unless the herbicides were applied on a vast scale, a move that would probably be politically impermissible, it could have little effect in heavily populated areas. 'There is just so much food in the Delta that crop-destruction missions here would have no real military value,' one official said.

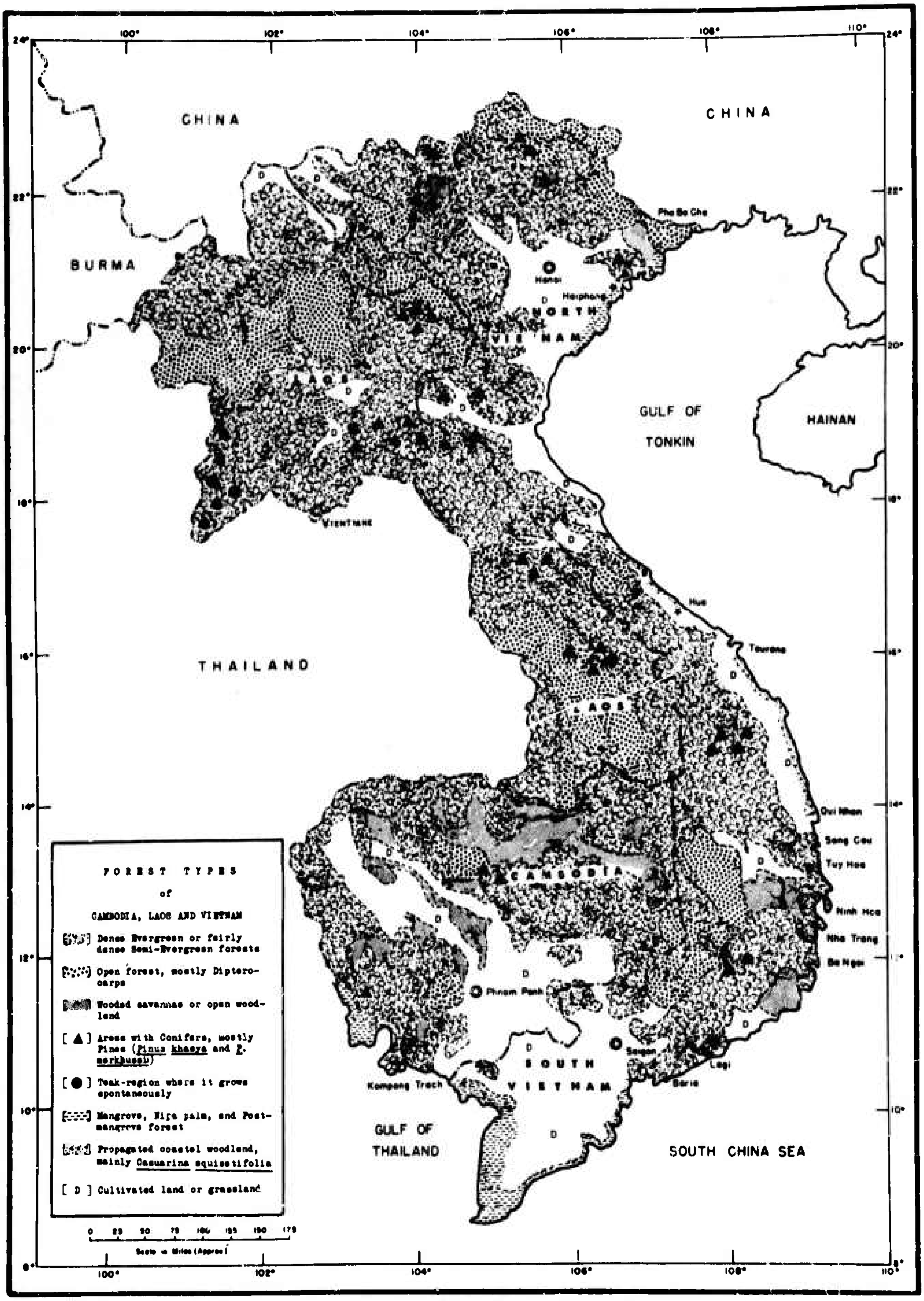
"Destruction operations are intended primarily for food fields in such Viet Cong base areas as War Zone D, north of Saigon, and in areas where growers are considered willing Viet Cong supporters.

"Some Viet Cong units are devoting as much as 50% of their manpower to growing food. . . .food shortages have become so acute in central Vietnam that some analysts expect the enemy to shift more of its military activity toward the North Vietnamese border, to ease the supply of provisions."(Pace, 1966)

Major Vegetation Types of Southeast Asia

The overall plant formations of Southeast Asia, and in particular the forests in Thailand and Vietnam, have been extensively studied and well documented in the botanical and forestry literature (Lecompte, 1907-1938, and Richards, 1952). Extensive investigations were first conducted by the French botanists and foresters (Chevalier, 1918 and 1929, Maurand, 1943). More recent studies of the vegetation in the area of the Mekong Delta (Duke, 1963, Van Cuong, 1960, and Duke, 1961, and the forests of Vietnam in general have been undertaken by specialists of the United States (Kernan, 1964). The most comprehensive of these recent investigations are "Vegetation of Southeast Asia: Studies of Forest-Types, 1963-1965" by Llewelyn Williams (1965), and "Forests of Southeast Asia, Puerto Rico and Texas" (Williams, 1967). The map (Figure V-5) from Williams' report shows the extent and distribution of various forest types in Vietnam and adjoining regions.

According to publications issued by French botanists, there are more than 1,500 species of woody plants in Vietnam, varying in size from small shrubs to large trees; hard-stemmed reeds to bamboos; and a wide variety of species of



Courtesy Lewellyn Williams

Figure V-5 - Major Forest and Vegetation Types in Southeast Asia palms, woody vines or lianes, and herbaceous plants. The major forest formations occurring in Vietnam include the following:

1. Evergreen, Broad-leaved Rain or Moist forests. Rain forest occurs in areas where the annual rainfall exceeds 100 in., is well distributed throughout most of the year, and with only a short dry period. True Rain forest is rather limited in distribution, being confined mainly to lower and middle elevations on mountain slopes. Evergreen Moist forest is found in areas where there are well defined wet and dry seasons of about equal length, and influenced by the monsoon climate.

2. Dipterocarp forest, probably the most extensive type, covering up to about 50% of the total forested area of Vietnam and neighboring countries.

3. Mixed Deciduous forest, usually heavily cut over and rather open.

4. Dry Evergreen forest, concentrated especially along river or stream banks.

5. Montane forest, containing oak frequently mixed with conifers, at middle and upper elevations.

6. Coniferous forest, in which species of pine (<u>Pinus</u>) form rather extensive stands in the uplands.

7. Swamp forests:

   a. Mangrove woodland, in coastal areas, especially in deltas and around river estuaries.

   b. Stands of nipa palm, also in deltas and tidal reaches, usually where mangrove occurs.

   c. Stands of cajeput (<u>Melaleuca</u>), in brackish water along the inner border or in the vicinity of mangrove.

   d. Fresh water swamps, generally in the interior.

8. Savannas, either open or sparsely wooded, and dominated by a ground cover of coarse grasses.

9. Thorn woodland, consisting of shrubs and small to medium-sized trees, many of which are armed with sharp spines, and often mixed with bamboo to form a tangle difficult to penetrate.

10. Bamboo brakes, frequently forming dense fringes along banks of streams and rivers, and develop rapidly in abandoned tilled land or when clearings are made in most types of forests.

Some of the forest associations in Vietnam, as in adjacent countries, are extremely complex in their floristic composition. The tallest (up to 100 ft or more), most dense and complicated type is an undisturbed Rain forest which, in some instances, may contain in an area of one acre up to 150 or more species of shrubs and small to large trees. Stands separated by only a short distance may show strikingly different features, particularly in their structure and the species present, so that their classification is oftentimes different. This diversity of forest composition in Vietnam, as in other tropical regions, may be ascribed to the variability of environmental conditions, influenced by climate, soil, drainage, and by human interference. The last named factor is in the form of felling for timber, routine burning, and the long established system of slash and burn or shifting agriculture, widely practiced especially by people inhabiting remote or mountainous areas in the interior.

Variability in floristic composition is shown in Table V-2, which inventories the principal species appearing in three strata or stories forming a Dry Evergreen forest, located on two test sites treated with herbicides in Thailand (Darrow et al., 1966). The two sites are situated in close proximity, one on the east side of the Pranburi River in the upper Peninsula, the other on the west side. It will be noted that Site I is nearly devoid of a ground layer of shrub growth. Site II, however, has a dense undergrowth, representing approximately 36% of the plants tallied. The following records, extracted from Williams' recent study, are especially pertinent to any ecological studies of the effects of herbicides and desiccants on the vegetation of this type of forest.

> "Forests of South Vietnam: The forests of South Vietnam have been devastated for many centuries. First nomadic or semi-savage people occupied the land and destroyed the forests without discrimination. After that came the Annamites who, in spite of a more advanced civilization, regarded the forest as capable of regenerating itself indefinitely, and gave no thought to its protection. Despite ample rainfall and other favorable conditions for growth, the forests were unable to re-establish themselves after prolonged periods of destruction. As a result, much of the vegetation that formerly covered Cochin-China, now forming southern South Vietnam, consists in the main of secondary growth, interspersed with scattered stands of primary forests.

Courtesy Lewellyn Williams

Figure V-6 - Rain Forest in the Mountains of Southeast Asia. "Khanun-nok" (Paloquin obovatum) is characteristic of moist tropical upland forests.

TABLE V-2

PERCENT COMPOSITION AND FREQUENCY OF PRINCIPAL WOODY SPECIES IN THE DOMINANT, INTERMEDIATE, AND SHRUB LAYERS OF TEST SITES I AND II

Species	Test Site I Composition (%)	Test Site I Frequency	Test Site II Composition (%)	Test Site II Frequency
Dominant Layer				
Lagerstroemia floribunda	0.2	84	4.9	96
Mansonia gagei	4.6	95	0.4	37
Diospyros coaetanae	0.7	81	1.2	68
Millettia leucantha	+a/	75	+	27
Dialium indum	+	23	0.9	74
Antheroporum pierrei	1.9	72	+	6
Diospyros mollis	+	67	+	46
Lagerstroemia loudonii	0.3	66	+	34
Spondias mangifera	+	35	+	66
Manilkara hexandra	0.6	61	+	39
Diospyros curranii	+	49	+	39
Garuga pinnata	+	37	0.5	47
Bambusa arundinacea	-b/	-	9.0	37
Grewia elatostemoides	+	4	1.5	29
Subtotal: composition	8.3		18.4	
Intermediate Layer				
Streblus zeylanica	45.0	100	9.5	22
Cleistanthus dasyphyllus	28.0	95	0.4	21
Celtis collinsae	0.7	92	0.2	40
Hydnocarpus ilicifolius	0.4	31	4.3	80
Vitex quinata	0.3	50	2.8	80
Atalantia spinosa	0.6	77	0.4	35
Diospyros cauliflora	1.2	76	+	45
Euphorbia trigona	3.2	75	0.6	24
Phyllanthus sp.	+	71	2.2	59
Niebuhria siamensis	+	48	+	72
Memecylon ovatum	6.9	66	12.1	48
Grewia tomentosa	+	18	3.4	66
Mitrephora keithii	0.9	64	+	2
Sindora maritima	+	5	0.6	62
Olea maritima	0.5	18	3.6	37
Phyllanthus emblica	+	3	0.6	27
Subtotal: composition	87.7		40.7	

TABLE V-2 (Concluded)

Species	Test Site I Composition (%)	Test Site I Frequency	Test Site II Composition (%)	Test Site II Frequency
Shrub Layer				
Cleistanthus sp.	+	19	16.2	95
Acacia comosa	+	46	14.5	91
Mezoneurum enneaphyllum	+	33	+	91
Capparis thorelii	+	38	0.7	90
Ventilago calyculata	0.3	87	+	55
Hymenopyramis brachiata	+	27	3.2	83
Zizyphus oenoplia	+	20	+	64
Sphenodesma pentandra	0.4	28	0.5	63
Jasminum sp.	+	14	+	51
Euonymus cochinchinensis	+	-	+	37
Hiptaga sp.	+	36	+	18
Actephila collinsae	+	22	+	33
Tarenna longifolia	+	5	+	32
Atalantia scandens	+	28	+	31
Combretum procursum	+	12	1.4	30
Subtotal: composition	0.7		36.5	
Total % Composition	96.7		95.6	

a/ Trace
b/ None

Source: Darrow (1966).

"Most of the burning of the forest in Annam, or Central Vietnam, is done, as elsewhere, for shifting cultivation, the 'rai' system widely adopted throughout Southeast Asia. In this process thousands of acres of forests are burned each year, followed by the planting of crops mainly for food. After two or three harvests, the patches are abandoned. Soon a series of grasses, particularly the ubiquitous Imperata cylindrica, sedges, and such weeds as Eupatorium odoratum develop. Even in normal times this practice of slash and burn is difficult to suppress among the tribes in the mountain areas, although it can be controlled to some degree in the plains, where people are in closer contact with authorities. In some instances during a single year the inhabitants of a large village may destroy a considerable area of forest within a radius of 10 to 15 miles. Bamboo brakes are also destroyed by fire. The effect of this deforestation over a long period is evident also in Central and North Vietnam, as shown by a gradual increase of uncultivated land along the base of mountains, caused by erosion of soil from the bare upper slopes, filling up the stream beds and with consequent floods."

Response of Vegetation to Herbicides

The response of foliage to chemical treatment varies markedly--from little effect to plant kill.

Reports from observers in Vietnam likewise vary. Some say that defoliation is temporary or relatively ineffective; others state that the trees are dead and bare. The following verbatim reports, while somewhat conflicting, are probably accurate:

"The chemical mixture is supposed to kill all trees and brush, but the withering and dropping of leaves may take five days to three weeks." (B: gart, 1962)

". . . begin turning foliage brown in a matter of hours, but full results are not visible for six months." (Miller, 1967)

". . . Double or triple canopy jungle generally requires two applications, with the second application four to six weeks after the first. . .gives effective vegetation control for nine to 12 months." (Farm Chemicals,. 1966c)

"Practically all the vegetation in the sprayed areas was dead and almost complete (estimated 95%) defoliation had resulted." (Armed Forces Chem. Journal, 1964c)

"Within several weeks they cause leaves on trees and other vegetation to wither away." (Washington Daily News, February 6, 1967)

". . . a powerful chemical killer which destroys all but the biggest trees. . ." (Lucas, 1967)

". . . within 24 hours the foliage begins to wither and turn brown; within five or six weeks, the leaves curl and fall." (Pruden, 1966)

"Within three days after a single spraying . . .the effects are noticeable. Within a week there is an 'autumn' effect. But three months must pass before the 'winter in Vermont' effect is achieved. Four months after that, however, the foliage begins to grow back." (Mohr, 1965)

Such diversity of reports is not surprising when consideration is given to:

* The remarkable number of woody plants found (1,500);
* The great diversity of plant communities found;
* Effects of seasonal changes; monsoons;
* Differences among herbicides used; and
* Application conditions which range from optimum to unfavorable.

Few if any scientific reports are available from the areas of operational use in Vietnam. The targets sprayed are frequently in enemy strongholds. The most useful data on response to herbicide treatment come from carefully conducted tests carried out in Thailand, Puerto Rico, and Texas (Tschirley, 1967c, and Darrow, 1966c). From these studies certain general observations have been drawn concerning the behavior of tropical vegetation and forest when aerially sprayed with military defoliants.

1. Degree of Defoliation: Maximum defoliation responses of 85 to 95% have been recorded, but complete defoliation of all species has not been obtained in any test plot of mixed forest.

2. Rate of Defoliation Response: The phenoxy herbicides and other systemic defoliants which are absorbed and translocated throughout woody plants produce abscission and leaf drop over a period of several months. Generalizations are difficult when dealing with so many factors, but perhaps two to three months are required as an average to reach maximum leaf removal.

Figure V-7 shows the defoliation response from "Orange" with maximum leaf drop between two and four months. At the end of seven months, the lianas have grown new leaves, and some of the foliage is returning to the trees.

Desiccants and contact herbicides produce leaf necrosis, loss of moisture and withering more rapidly; about two to three weeks on the average.

Similar photos, Figure V-8, show the desiccation achieved from cacodylic acid ("Blue"). In three weeks the leaves have curled, and most have fallen. Regrowth is under way three months after treatment. Table V-3 compares the percentage of defoliant obtained with various herbicides for a period of one year.

More detailed data are presented for various rates of application and other agents in the Appendix, Tables A-1 (p.297), A-2 (p.301) and A-3 (p.303).

3. Duration of Defoliation: Some trees and other woody plants are killed; others show topkill only. Many trees recover, growing new leaves within a year. Root sprouting occurs with some species. Certain species of trees, including Streblus zeylanica, Hydnocarpus ilicifolius, and several Diospyros spp. are relatively resistant to defoliation. Detailed analysis of species response is being compiled (Darrow, 1966d).

Figure V-9 shows the influence of application rate on the duration of effective defoliation, and length of time to 50% recovery.

It is problematical whether trees exhibiting complete defoliation like that of Figure V-10 will recover. The percentage of trees in mixed forest stands which show total kill after 12 months or longer has elasped is not known.

4. Seasonal Effects: Woody plants in areas having seasonal rainfall are seasonally susceptible to herbicides. The most susceptible period occurs when soil moisture has been adequate for rapid growth. The defoliation response to all systemic herbicides such as "Orange," "White" and "Purple" was more rapid and more complete during the rainy season, with its generally favorable soil moisture and growing conditions, than during the dry season. Lower rates of chemical treatments are necessary during periods of active growth.

Before Treatment, February 1965

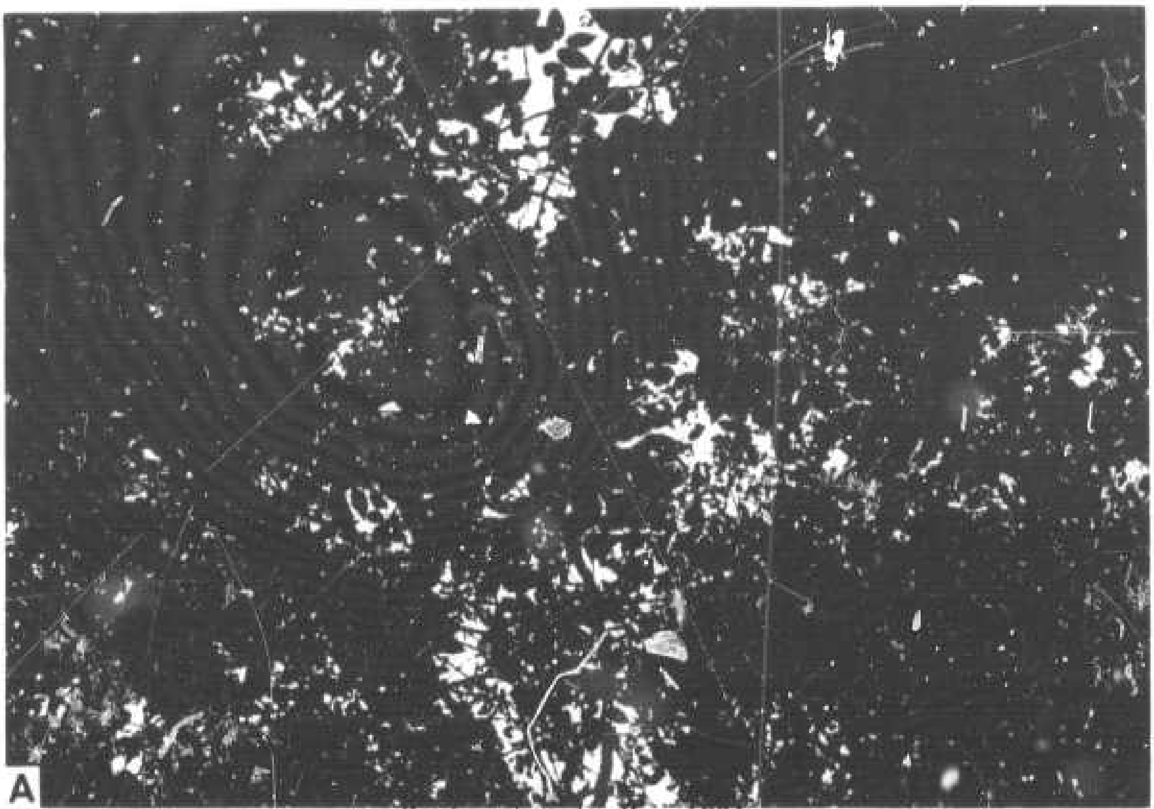
Two Months After Treatment

Figure V-7 - Defoliation Response from Orange Applied at 2.4 Gal/Acre (21 Lb/Acre AE)
(Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Four Months after Treatment

Seven Months after Treatment
(Note the regrowth of vines)

Figure V-7 (Concluded)



Pretreatment, May 1964

Three Weeks after Treatment at Maximum Effect

Figure V-8 - Defoliation Response from Blue (cacodylic acid) Applied at 1.5 Gal/Acre (4.5 Lb/Acre AE) (Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Three Months - Showing Regrowth

Figure V-8 (Concluded)

TABLE V-3

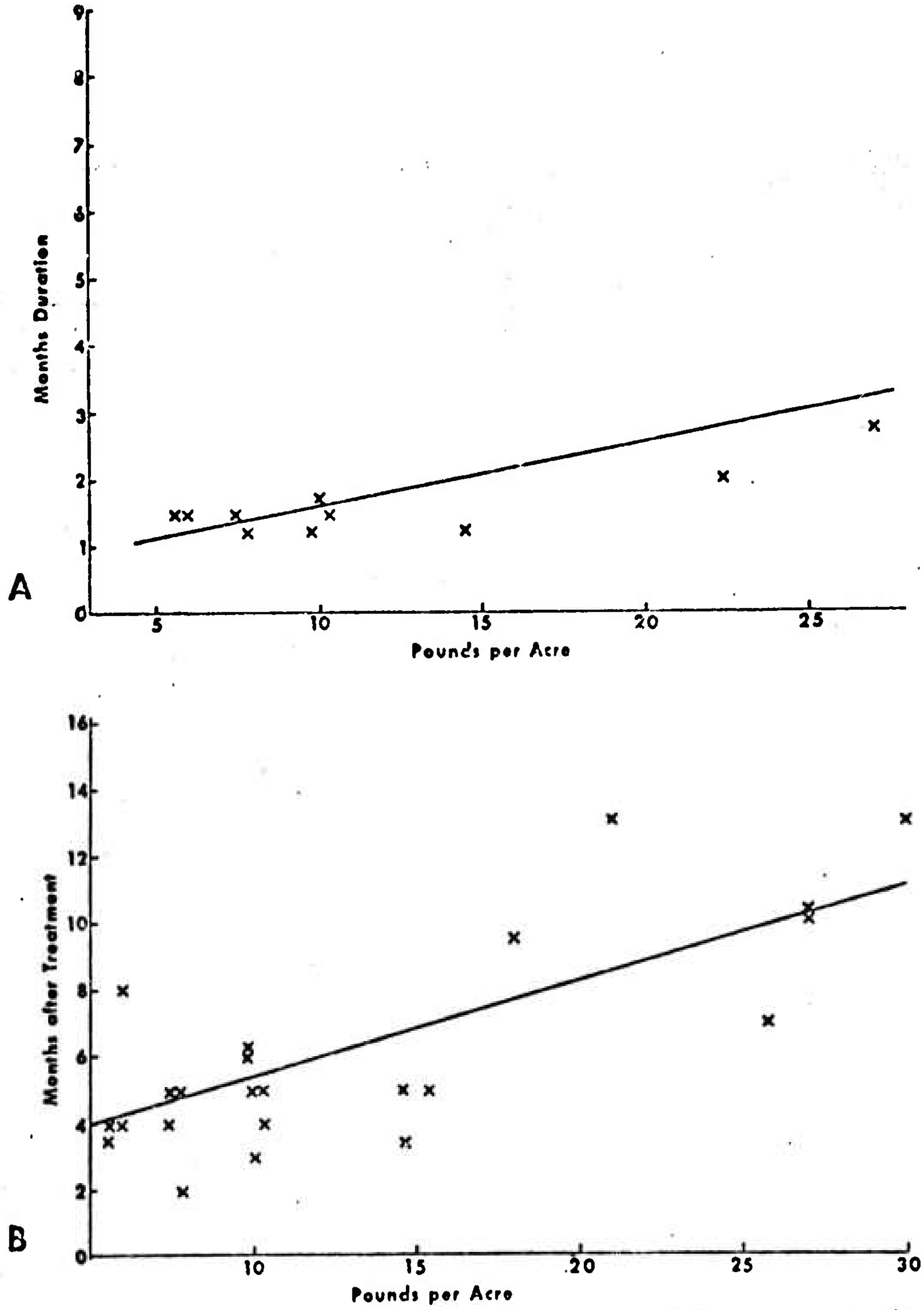
THE PERCENTAGE OF DESICCATION AND DEFOLIATION RESULTING FROM HERBICIDES APPLIED AS LOW-VOLUME AERIAL SPRAYS ON RAIN FOREST VEGETATION

Herbicide[a]	Treatment Gal/Acre	Treatment Lb/Acre	Time After Treatment 1 Wk. (%)[b]	2 Wk. (%)	1 Mo. (%)	3 Mo. (%)	6 Mo. (%)	1 Yr. (%)
Orange	1.5	12	9/3	53/28	69/61	65	52	38
→	3.0	24	19/8	73/32	89/73	79	66	54
	6.0	48	28/10	79/37	89/75	91	71	61
Picloram	1.5	3	8/0	24/14	34/32	29	27	30
→	3.0	6	8/0	51/21	70/52	80	60	54
	6.0	12	19/9	51/22	78/66	83	76	74
2,4,5-T Plus Picloram	1.5	7.5	7/3	25/14	42/39	52	40	45
(4:1) →	3.0	15	3/0	25/5	39/32	42	46	51
	6.0	30	7/0	38/13	62/45	77	73	69
Paraquat	1.5	3	15/9	25/18	27/25	19	9	10
→	3.0	6	29/13	51/29	68/63	51	41	30
→	6.0	12	38/23	53/35	60/56	43	15	17

a/ Arrows denote typical rates.

b/ The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

Source: (Tschirley, 1967).



Source: Tschirley (1967)

Figure V-9 - Duration of Defoliation Response from Application of Purple as Related to Dosage Rate.

A. Duration of maximum percent decrease in obscuration. Data represent mean treatment values.

B. Number of months until 50% recovery from maximum response. Data represent individual plot values.

Before Treatment, December 1964

Three Months After Treatment

Figure V-10 - Defoliation Response from Purple Applied at 3.0 Gal/Acre (26.7 Lb/Acre AE)
(Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Six Months After Treatment

Nine Months After Treatment

Figure V-10 (Concluded)

In areas such as evergreen and broad-leaved Rain forest where rainfall is high but uniformly distributed throughout the year, woody plants are less subject to seasonal susceptibility.

Seasonal effects are reflected in the level of treatment needed for effective defoliation of mixed forest stands of different canopy density. These herbicide levels are summarized in Table V-4. More detailed conclusions regarding herbicide effects observed in tropical forest tests are presented in the Appendix, pp. 294-296, Figure A-1 (p.299), and Figure A-2 (p.300).

Revegetation and Succession

Tropical forest stands sprayed with quantities of systemic herbicides sufficient to kill or produce more than 85% defoliation show a general pattern of revegetation similar in some respects to that found in abandoned forest clearings. The seral successions observed in these devegetated areas have been described by Llewelyn Williams (Tschirley, 1967c).

The forests of Southeast Asia, and Puerto Rico have suffered severely over the centuries from human disturbance through falling of trees for construction timbers, fuelwood, and charcoal, or to clear land for agricultural use. Considerable changes in the vegetation have been caused by fires, either spontaneously or deliberately set, grazing by domesticated animals and wildlife, and damage by insect pests. In Puerto Rico much of the forest land area has been cleared for agricultural use, and the remainder is almost entirely secondary forest. Only about 1 or 2% of the total area of the island consists of stands of primary forest. In Southeast Asia, also, the forests have been devastated for centuries. Only in the mountainous, less accessible regions are there extensive, undisturbed stands of pines and hardwoods of commercial value.

The tropical Rain forest is a prime example of a plant community in which rainfall, soil, and vegetation are the principal factors that contribute to the maintenance of a complex equilibrium. When one of the components of the primary forest is partly or completely destroyed, the other factors are altered and a new type of plant cover appears that is adapted to the modified environment.

The general pattern of regrowth is essentially the same in tropical America as in Southeast Asia. Revegetation of disturbed areas follows a similar sequence in development of secondary growth, and the successional plant communities are similar in structure and phytosociology, but the species, of course, may be entirely distinct.

TABLE V-4

INFLUENCE OF SEASON AND FOLIAGE DENSITY ON HERBICIDE TREATMENTS REQUIRED FOR EFFECTIVE DEFOLIATION

Defoliation Requirement	Chemical	Rainy Season: Light to Moderate Cover (Single Canopy)	Rainy Season: Dense Cover (Multiple Canopy)	Dry Season: Light to Moderate Cover (Single Canopy)	Dry Season: Dense Cover (Multiple Canopy)
Fast, Short-Term Defoliation or Desiccation	Cacodylic Acid	5 to 6 lb/acre in 2.5 to 3.0 gal. spray	5 to 6 lb/acre in 2.5 to 3.0 gal. spray	5 to 6 lb/acre in 2.5 to 3.0 gal. spray	5 to 6 lb/acre in 2.5 to 3.0 gal. spray
		Equal to Blue (65% cacodylic acid) at 7.7 to 9.2 lb/acre	Repeat application may be needed in 2 to 3 weeks for effective defoliation at ground level	Equal to Blue (65% cacodylic acid) at 7.7 to 9.2 lb/acre	Repeat application may be needed in 3 to 4 weeks for effective defoliation at ground level
Effective Defoliation (60 to 75%) for Moderate Duration, 3 to 4 Months	Purple or Orange	1.5 to 2.0 gal/acre undiluted or in 1:1 mixture with diesel fuel	2.0 to 2.5 gal/acre undiluted Repeat application may be needed after 2 months	2.5 to 3.0 gal/acre undiluted	2.5 to 3.0 gal/acre undiluted
Maximum Defoliation and Duration, 6 months or more	Purple or Orange	2.5 to 3.0 gal/acre undiluted	2.5 to 3.0 gal/acre undiluted Repeat application may be needed after 2 months	2.5 to 3.0 gal/acre undiluted	3.0 or more gal/acre undiluted Repeated application may be needed in following rainy season

Source: (Darrow, 1966d).

Forest Underbrush before Treatment, February 1965

Ten Months Following Treatment, December 1965

Figure V-11 - Herbicide Treatment Improves Horizontal Visibility Reducing the Opportunity for Ambush (Courtesy F. Tschirley)

The first stage of successional growth that develops following disturbance of dense, humid forest is usually dominated by grasses and weeds. These are generally short-lived, of less than one year. As a rule, in cleared areas such as those abandoned in shifting agriculture the plants that develop in the initial stage of secondary growth are entirely different from those that grow in the primary forest; likewise, seldom do any species in the secondary growth appear in the primary forest. Forest stands disturbed by the application of herbicides may show appreciable regrowth of seedlings representative of the original woody plants due to root sprouting, from seeds present in the soil, or seedlings that may have survived the treatment.

The next phase may be dominated by shrubs, followed by trees of quick growth. Or the succession may lead almost directly from the herbaceous stage to tree dominance. The secondary forest is usually composed of fast-growing trees with soft wood, and their seeds are wind or animal dispersed.

In Thailand two weeds that develop most abundantly in abandoned land and in forest clearings are *Eupatorium ordoratum*, and the ubiquitous grass (*Imperata cylindrica*). Both plants are light loving and cannot thrive under shrubs and trees. Later the ground is colonized by shrubs. The shrub stage is followed by the development of a secondary forest in which trees of the genera *Bombax*, *Dillenia*, *Vitex*, and *Grewia* appear, and in humid sites species of wild bananas (*Musa*) appear. In many areas in Thailand, as in the other Mekong Basin countries, the weeds, grasses, and shrubs are gradually dominated by bamboos, particularly species of *Bambusa* and *Thyrsostachys*, which may even suppress the development of trees. This is particularly noticeable in cutover stands of teak, as well as in the humid Evergreen forest.

Successional growth in the Rain forest of tropical America is similar in structure to that of secondary Rain forest in Southeast Asia, although it is quite different, of course, in floristic composition. The ubiquitous grass (*Imperata cylindrica*) is widely distributed in the Old World tropics and readily develops in forest clearings. This weed does not occur in tropical America except in Chile, but *I. brasiliensis* and other grasses are analogous. Intertwining sedges of the genus *Scleria*, with sharp-edged leaves, often form an almost impenetrable tangle in secondary forests of tropical America. In Puerto Rico, as elsewhere in tropical America, among the most frequent trees in secondary forests are "Yagrumo hembra" (*Cecropia*) and "Yagrumo macho" (*Didymopanax*). Both propagate naturally and their growth is rapid.

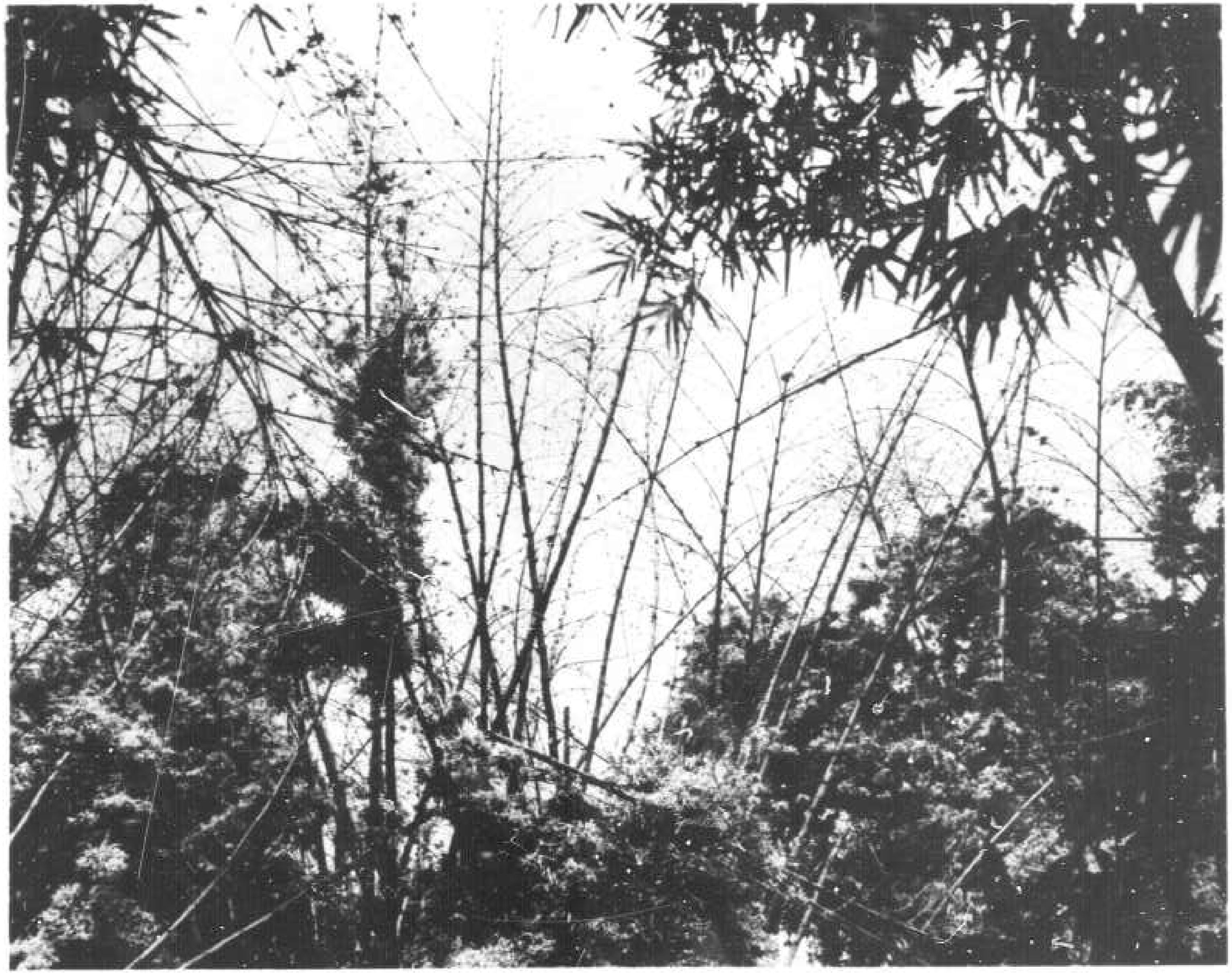


Figure V-12 - Revegetation after One Year in Forest Opening Created by Heavy Application of Herbicide. Bamboo forest is the dominant successor, with various grasses and woody plants covering the ground layer. (Courtesy F. Tschirley)

Extent of Herbicide Application

There has been a steadily increasing pace in defoliation flights since the first operational employment of herbicides.

In the last two months of 1962, when spray flights first started, only 60 missions were flown. Only 107 missions were logged in all of 1962 (Pruden, 1966); however, by 1966 over 3,000 sorties were flown (Bloomington Daily Herald, 1966).

Chemical consumption shows that over 90% of the herbicides sprayed are systemics (Orange, White or Purple), while considerably less than 10% has been cacodylic acid for desiccation and destroying rice.

The following table shows the approximate extent and distribution of herbicide application from 1962 to date.

ESTIMATED* AREA HERBICIDALLY TREATED** IN SOUTH VIETNAM

Year	Acres Sprayed/Year		
	Defoliation	Crop Destruction	Total of Both
1962	17,119	717	17,836
1963	34,517	297	34,814
1964	53,873	10,136	64,009
1965	94,726	49,637	144,363
(Jan.-June 1966)			(495,637)
1966	775,894	112,678	888,572
(Jan.-Sept. 1967)	843,606	121,400	965,006

Sources: DoD data, contained in various releases.

* Not actual land area measurement. Areas were estimated from the number of sorties flown, calibrated spray rates and average width of spray swath covered.

** Treated area includes all respraying. Some areas are retreated annually (or more often if needed); no estimate is available on the extent of reapplication. The actual area is believed to be substantially lower than the figures here show.

VI. TOXICOLOGICAL EFFECTS OF HERBICIDES

A. Introduction

As pointed out in an earlier section of this report, larger and larger quantities of herbicides are being applied each year to our forests, rangelands, rights-of-way, lakes and waterways, for the management of unwanted vegetation. Some of these chemicals have been around for a long time and we know pretty well how they should be handled so as to minimize the risks associated with their used. Others of the herbicides are newer and the potential hazard associated with their use is less well known. Since this report is oriented toward an understanding of the ecological consequences of using herbicides, this section on toxicology must take a broad approach and present a judicious selection of information available on all of the living forms which might in some way come into contact either directly or indirectly with the herbicides. In the case of the chlorinated insecticides such as heptachlor or DDT, the birds were killed because earthworms concentrated the insecticide and magnified the concentrations received by the birds. Therefore, we are presenting information on the possible retention and/or accumulation of herbicides in animals, insects, birds, etc. Another subject considered here is the question of possible carcinogenicity of the herbicides and the likelihood that at some future date we may experience a large increase in the incidence of human, animal or fish cancer as a result of the use of herbicides. The question of teratology, that science dealing with pathologic changes occurring during embryonic development, is one for which information is now available for some of the herbicides and is discussed briefly. Still another area for concern is the possible human toxicity which may result from skin absorption, contact with eyes or through inhalation of herbicide aerosols by persons who may be inadvertently sprayed with them as might occur, for example, during the defoliation of the forest in Vietnam. Since herbicides have been used both for controlling weeds in crops and also for crop destruction we are discussing two other toxicity problems (1) the effect of herbicides on the growth of microorganisms in the soil and (2) the possibility that the herbicides possess mutagenic activity and change the genetic character of the plants and/or animals. Although complete answers will not be found to all the questions raised, we have made an effort to present the information which we believe to be relevant to a thoughtful consideration of them.

For this information survey we have concentrated our efforts on those herbicides which have found extensive use in noncroplands and these are listed in Table II-2 along with a brief comparison of their acute oral toxicity to rats. It is our hope that a consideration of the use-parameters and toxicities of these herbicides will provide perspective for the reader.

Section B of this chapter is arranged according to the names of the individual noncropland herbicides; we have used the recommendations of the Weed Society of America in the choice of chemical designation and spelling. Under each individual herbicide name may be found a brief description of the toxicity of that herbicide to man (if known), laboratory animals, livestock, insects, fish and fish food organisms.

Section C entitled, "Effects of Herbicides on Microorganisms,' could have been broken down and listed under the individual herbicides in Section B; however, it seemed more meaningful to have a brief discussion of the general importance of microorganisms in an ecosystem and to note effects of herbicides upon them.

In Section D of this chapter will be found an assortment of information including: (1) some experiments on the possible mutagenic activity of the phenoxy herbicides, (2) a report on a change in insect populations from the use of herbicides, (3) a comparison of the accumulation of herbicides in a number of fish, (4) a discussion of the relative importance of selecting the formulation as well as selecting the herbicide for aquatic weed control, and (5) some general conclusions reached by an examination of these toxicological data.

The relative toxicity of herbicides is usually determined by a comparison of the acute oral toxicities in rats:

Class	Acute Oral Toxicity LD_{50}, mg/kg	Lethal Dosage for 150 Pound Man
Highly toxic	50 and below	Few drops to 1 teaspoon
Moderately toxic	50 - 500	1 teaspoon to 1 ounce
Mildly toxic	500 - 5,000	1 ounce to 1 pint or 1 pound
Nontoxic	Above 5,000	1 pint to over 1 quart

Results of toxicological tests often are expressed as the number of milligrams of toxicant per kilogram of test animal (mg/kg) that will kill 50% of the test animals (LD_{50}). Effects of toxicants on aquatic animals resulting from contamination of the water often are expressed as the number of parts of toxicant per million parts of water (ppm), and mortalities may be expressed in terms of the median tolerance limit (TLm). The following tabulation gives the equivalent parts per million (in 12 in. of water) and milligrams per square foot of various rates of application. Some herbicide applications are very heavy (several hundred pounds per acre) (George, 1960).

Pounds per Acre	Milligrams per Square Foot	Parts per Million in 12 in. of Water
0.1	1.0	0.04
0.5	5.2	0.2
1.0	10.4	0.4
2.0	20.8	0.7
5.0	52.1	1.8
10.0	104.1	3.7
100.0	1041.3	36.9

B. Toxicity of Noncropland Herbicides

Amitrole

Amitrole, 3-amino-1,2,4-triazole, was introduced for the defoliation of cotton and since has been used extensively for the control of weeds and grasses in noncropland areas. Its toxicity to man is unknown which, as the Merck Index (1960) suggests, may be an indication that it is not very toxic. In a survey of pesticides which have caused human fatalities, Hayes (1967), listed only these eight herbicides: acrolein, 2,4-D, dalapon, MCPA, paraquat, sodium chlorate, 2,4,5-T and TCA. Again the absence of amitrole from this list is indicative of its lack of extreme toxicity to humans. The acute oral toxicity of amitrole for mice listed by the USDA, Agriculture Handbook 332 (1967) is 5,000 mg/kg. The acute oral toxicity of amitrole in rats as supplied by the manufacturer and given in the Herbicide Handbook WSA (1967) is 25,000 mg/kg. The results of a two-year feeding study in rats show that it is a goitrogen which is less potent than thiouracil. This report is in sharp contrast to the unpublished report of the Food and Drug Administration that amitrole, alias aminotriazole, is a carcinogen and produces thyroid tumors in rats (Business Week, 1959a and 1959b). The best explanation available in the open literature about the "carcinogenesis" of amitrole is the review of Dalgaard-Mikkelsen and Poulsen (1962) from which we quote:

> "No signs of poisoning were seen after intravenous injection of 1,750 mg/kg to a cat (Shaeffer, 1956), of 1,600 mg/kg to mice (Shaeffer, 1956), or 1,200 mg/kg to a dog (Weir et al., 1958). A single intraperitoneal dose of 4,000 mg/kg was tolerated by mice, whereas 21 doses of 1,000 mg/kg each to rats, distributed over 45 days, produced an increase of the thyroid weight of 328% in males and 410% in females, while at the same time the growth and intake of food were found to be normal (Shaeffer, 1956).

"In feeding experiments on rats extending over 68 weeks, no effect was seen on the growth or intake of food at 10 and 50 ppm in the diet, as compared with controls, whereas 100 ppm caused a decrease in growth and food intake in male rats during the last few experimental weeks. However, in male rats given 50 ppm the thyroid became enlarged after 13 weeks (Weir et al., 1958). Investigations into the effect on the thyroids of rats of two years of feeding with aminotriazole are stated to have given the following results: In the control group, there was found one case of cystic follicle with papillary changes, while among the animals given 10 ppm one out of 10 examined presented adenoma; further, after 50 ppm two out of 15 examined had adenoma and one apparently adenocarcinoma. Rats given 500 ppm of aminotriazole in the diet for 17 weeks, which were then retained on a diet free of the compound for two weeks prior to sacrifice, appeared to have normal thyroids at the time of sacrifice (Jukes and Shaeffer, 1960).

"The observation that rats fed with 100 ppm of the compound for two years 'developed a significant number of thyroid adenomas and adenocarcinomas,' as well as the demonstration of residues of aminotriazole in marketed cranberries (Science, 1959), caused prohibition of sale of cranberries and cranberry products of the 1958 and 1959 crops from certain parts of the United States. Furthermore, it resulted in an official announcement from the Secretary of Health, Education, and Welfare that the reason for the prohibition was 'possible contamination by a chemical weedkiller, aminotriazole, which causes cancer in the thyroid of rats' (Flemming, 1959). In the ensuing discussion, doubts were raised as to whether the marked antithyroid action of aminotriazole can justly be characterized as carcinogenic (Astwood, 1960, and Jukes and Shaeffer, 1960).

"The mechanism of the antithyroid action of aminotriazole seems, on the basis of experiments on rats, to be identical with that of thiouracil derivatives (Alexander, 1959a and Jukes and Shaeffer, 1960). The absorption of I^{131} by the thyroid is depressed in both rats (Alexander, 1959a) and humans (Astwood, 1960), because its incorporation as organically bound iodine is obstructed (Alexander, 1959a). Following injection of aminotriazole, a reversible inhibition has been noticed of the catalase activity in thyroid tissue (Alexander, 1959a) as well as in kidney and liver tissues (Hein et al., 1955, Hein et al., 1956, and Tephly et al., 1961). However, to obtain a definite inhibition of the catalase activity, larger doses of aminotriazole are required than are necessary to depress the absorption of I^{131} by the thyroid (Alexander, 1959a). Hence, inhibition of catalase activity can hardly account for the antithyroid action. Studies, in vitro, using purified catalase preparations from liver and red blood corpuscles, have under special experimental conditions shown irreversible inhibition (Margoliasch and Novogrodsky, 1958).

"However, the results of experiments with thyroid tissue suggest that inhibition of thyroid peroxidase is the essential factor (Alexander, 1959b), a hypothesis that is borne out by the results of experiments with peroxidase from milk and vegetable tissue, which are likewise inhibited by aminotriazole (Castelfranko, 1960). It should be added, however, that the question has not yet been clarified, since enzymes that are active in the purine metabolism of bacteria are also inhibited, in these cases reversibly by aminotriazole; this observation is utilized experimentally (Rabinowitz and Pricer, 1956, and Weyter and Broquist, 1960)."

A. J. Lehman (1965), Director of Pharmacological Research at the Food and Drug Administration, has prepared the following general statement about the appraisal of safety of chemicals in food, drugs and cosmetics. He states, "the time of appearance of tumors is important in the assessment of carcinogenicity of a compound. Substances that induce tumors in young animals are considered highly carcinogenic while those inducing tumors after one year or in the last month or two of a lifetime feeding study are of lesser significance. Most spontaneous tumors appear in rats after one year of age."

Napalkov (1963) conducted prolonged treatments of rats with 3-amino-1,2,4-triazole and thiouracil and obtained precancerous lesions. When these treatments were combined with goitrogens and androgens stress accelerated the appearance of neoplasms while estrogens delayed them. We are inclined to agree with Jukes and Shaeffer (1960) that the term "carcinogen" probably should not be applied to amitrole since the effects on the thyroid are reversible when the treatment is discontinued and since we do not consider antithyroid compounds normally occurring in the diet as carcinogenic.

Studies on the toxic effects of amitrole on mallard ducks have been conducted at the Patuxent Wildlife Research Center. First experiments indicate that the LD_{50} is probably greater than 5,000 ppm (unpublished findings of Dewitt and Menzie cited by George, 1960).

Fang et al. (1964) have conducted a study on the metabolism of 5-C^{15} amitrole fed to rats. During the first 25 hr 70 to 95.5% of the radioactivity was found in the urine which contained two radioactive metabolites in addition to the amitrole. Liver was shown to be site of metabolite-1 formation and the rate of elimination of this metabolite was much slower. There was no accumulation of amitrole in the fatty tissues.

C. E. Bond has studied the toxicity of various herbicides to fish and reported these at a seminar on "Biological Problems in Water Pollution," which is cited in a review by Lawrence (1962). Largemouth bass were able to tolerate 1,000 ppm of amitrole in an aquarium for 48 hr but this same concentration in a running stream killed all of them during a six-day test. At a concentration of 62.5 ppm the largemouth bass were able to survive for 14 days. The median tolerated limit for Coho salmon was 325 ppm for 48 hr. It is judged therefore that amitrole is not toxic to fish at the levels which are likely to be encountered in aquatic weed control.

Crosby and Tucker (1966) report that at 23 ppm amitrole immobilizes Daphnia magna while the recommended level of use in ponds and lakes is < 10 ppm. They suggest, however, that this herbicide may significantly influence the abundance of this organism for use as food for fish.

The effect of amitrole on soil microorganisms is probably slight since microbial attack in warm moist soil is an important method of its disposition. Kaufman (1966) has reported that by means of soil enrichment techniques it is possible to develop a culture of microorganisms which destroy dalapon very rapidly. The addition of 5 to 100 ppm of amitrole greatly decreases the rate of decrease of dalapon. In the reverse situation dalapon does not affect the rate of removal of amitrole from the soil.

Amitrole-T is a mixture of amitrole and ammonium thiocyanate which is very effective in the control of certain aquatic weeds such as water hyacinths. The acute oral toxicity of ammonium thiocyanate in rats is 750 mg/kg (Herbicide Handbook WSA, 1967). The toxicity of the mixture is thought to be about the same as ammonium thiocyanate.

In spite of the "cranberry scare" this writer is of the opinion that amitrole has not been proved to be carcinogenic and its use does not represent any unusual hazard. In fact it appears to be one of the least toxic of the herbicides now in use. The toxicity of amitrole to those fish which have been studied appears to be unusually low.

Atrazine

2-Chloro-4-ethylamino-6-isopropylamino-s-triazine or atrazine is much like simazine chemically but it is more effective in the control of some plants such as horsetail, Indian hemp, prickly lettuce, yellow nut grass, rush, sedge and Canada thistle (Dunham, 1965). Geigy Agricultural Chemicals, Division of Geigy Chemical Corporation, has supplied the following information on the toxicity of atrazine (Herbicide Handbook WSA, 1967): No case of human poisoning from the ingestion of atrazine has been reported. The acute oral toxicity to rats is LD_{50} = 3,080 mg/kg and in mice is 1,750 mg/kg. Two-year feeding studies with both male and female rats fed various levels of atrazine in the diet (up to 100 ppm) showed no gross or microscopic changes due to the atrazine.

Toxicity studies with atrazine in sheep and cattle were conducted by Palmer and Radeleff (1964). Sheep died after two daily doses of 250 mg/kg, 16 daily doses at 100 mg/kg and 199 doses at 50 mg/kg. Cattle succumbed to two daily doses of 250 mg/kg each. The animals which died showed signs of compound degeneration and the observed discoloration of the adrenal glands was most remarkable. Lungs, liver and kidneys were heavily congested and undigested food was found in the rumen. No deaths or toxic symptoms resulted from a 1 hr exposure of rats to an aerosol of Atrazine 80W (80% atrazine as a wettable powder). The atrazine concentrations ranged from 1.8 to 4.9 mg/liter of aerosol (Herbicide Handbook WSA, 1967).

Toxicological investigations conducted with bobwhite, quail and mallard ducks, have shown atrazine to have a very low toxicity to these species.

Norris et al. (1967) harvested deer at various time intervals following the application of atrazine to forest lands for grass control. Various organs and body tissues were removed. Results are given for three animals harvested from two different treatment areas.

Tissue Organ	Statement
Blood	Less than 12 to 77 ppb*
Brain	Less than 48 ppb
Feces	From less than 96 to less than 360 ppb
Heart	From 15 to 76 ppb
Kidney	13 to 60 ppb
Liver	25 to 75 ppb
Meat	From less than 22 to 36 ppb
Spleen	From 24 to less than 48 ppb
Stomach Contents	From 178 to 3,453 ppb
Thyroid	Less than 200 ppb
Urine	Less than 60 ppb

* ppb = parts per billion.

They found no atrazine residues greater than 76 ppb in portions of the animal which are normally used for human consumption. The length of persistence of the chemical in these tissues is not clear. "The likelihood of encountering dangerous residues of atrazine in tissues of importance for human consumption appears low."

Unpublished results of R. O. Jones on the effect of atrazine on the survival of the fry of common warm-water fishes to some chemicals employed in fish culture has been cited by Lawrence (1964). Largemouth bass, channel catfish and bluegill fry tolerated 5, 10, and 10 ppm of atrazine, respectively, for 96 hr.

In studies of herbicides for aquatic use, Walker (1964) applied atrazine at rates varying from 0.2 to 6.0 ppmw for the control of filamentous algae. During these studies, there was no observed fish killed even though he concluded that atrazine is about twice as toxic as simazine: LD_{50} for sunfish = 10 ppm, LD_{10} = 5 ppm.

Atrazine also proved to be somewhat toxic to bottom fauna as judged by an approximately 50 percent drop in total numbers of organisms and also in the total weights of organisms: Mayflies (Ephemeroptera) caddis flies (Tricoptera), leeches (Hirudinea) and gastropods (Musculium).

We conclude that there is not likely to be much acute animal toxicity from the use of atrazine. However, the decrease in numbers of fish food organism may reduce the numbers of fish in areas where fish movement to new feeding grounds is restricted.

Boron Compounds

The sodium salts of borate, metaborate, tetraborate and pentaborate--but particularly the tetraborate--are used as nonselective soil sterilants or in combination with other herbicides such as monuron, bromacil, TBA, fenuron, diuron, 2,4-D and sodium chlorate. Often the rates for application of these borate mixtures are very high and may reach 1,000 to 3,000 lb/acre (Klingman, 1961). The acute oral toxicity to rats is 5,560 mg/kg (hydration not specified) (Herbicide Handbook WSA, 1967). Borax used as a herbicide or soil sterilant has not been a hazard to livestock or wildlife (Rowe, 1951).

Bromacil

The herbicidal activity of 5-bromo-3-sec-butyl-3-methyluracil, bromacil, was first reported by Bucha et al. (1962), and since that time has gained acceptance for use on noncroplands for the control of both grasses and broadleaf weeds. Hilton et al. (1964) and Hoffman et al. (1964) have shown it to be a direct inhibitor of photosynthesis and that it acts at the chloroplast level. We have found no reports of human fatalities resulting from the use of bromacil; this is not surprising in view of the low acute oral toxicity in rats, namely, LD_{50} = 5,200 mg/kg (Herbicide Handbook WSA,1967). In tests on the intact and abraded skin of guinea pigs, a 50% aqueous suspension of the 80% wettable powder was mildly irritating to the skin of young animals but more irritating to the skin of older animals. It did not produce allergic skin sensitization.

Palmer (1964) studied the oral toxicity of six different herbicide formulations in female sheep and observed that one sheep given five daily doses of 250 mg/kg of bromacil showed severe toxic symptoms including lameness and incoordination but survived. In a second sheep given 11 daily doses of 100 mg/kg of bromacil it lost 10% of its weight but otherwise appeared normal; it regained the lost weight upon termination of the treatment.

The question has been raised about the possible mutagenic activity of bromacil because of its structural similarity to 5-bromouracil which is readily incorporated into cellular deoxyribose nucleic acid and which is a mutagenic agent. Studies by McGahen and Hoffman (1963 and 1966) showed that bromacil does not induce a reversion of AP72 phage in the presence of thymine primed *Escherichia coli* and that bromacil is not incorporated into the DNA. These findings show that mutagenicity does not appear to be characteristic of bromacil.

Based on a consideration of application rates between 1.5 and 24 lb/acre we do not now foresee any toxicity problems due to direct toxicity to humans or animals.

Cacodylic Acid

Dimethylarsinic acid or cacodylic acid is a newcomer to the herbicide field although the chemical has been around for many years. It is useful as a desiccant causing leaf-drop and for the killing of certain hardwood species. The recommended application rate is 22 lb. acid equivalent (ae) per acre but in some cases rates up to 50 lb/acre have been employed (Crafts, 1961) for soil sterilization (99% kill after 1.5 months at the highest level). The present paragraphs are devoted to an evaluation of the potential hazard associated with the use of this material as an aerial spray or by the other common dissemination methods. Commercial cacodylic acid is a white crystalline material which is readily soluble in water but is frequently obtained mixed with sodium chloride or dissolved in water. Depending upon the formulation chosen it may contain from 25 to 77% cacodylic acid (acid equivalent); therefore, attention must be paid to the label statement showing the cacodylic acid content or its equivalent in the case of formulations containing the sodium salt of cacodylic acid. During manufacture an attempt is made to minimize the content of trivalent arsenic as its presence increases the toxicity of the final product to animals. The material designated as "blue" by the military agencies contains 65% cacodylic acid (Brown, 1962)* and less than 0.1% trivalent arsenic.

* The Ansul Chemical Company reports that currently "blue" consists of sodium cacodylate at 3.1 lb. acid equivalent/gal.

Sollman (1950) describes cacodylic acid as a material which has medicinal properties similar to those of inorganic arsenic "to which it is partly reduced in the body." Since the reduction is slow the toxicity is reduced but the effects last longer. Preliminary experiments by Peoples (1964) are contradictory and indicate that no reduction to trivalent arsenic occurs since administration of cacodylic acid to cows followed by analysis of tissues showed only the pentavalent arsenic to be present. However, since cacodylic acid is reported to be a methyl donor in transmethylation processes (Ciusa and Barbioli, 1963), one should not be surprised to find in vivo metabolites containing only one or neither of the methyl groups. Cacodylic acid, especially when given by mouth, imparts a garlic odor to the breath, sweat, and urine. The dosages which have been given to humans as pills or as hypodermic injections vary from 0.025 to 0.15 g/day; Sollman adds, however, that cacodylate is not effective in the chemotherapy of syphilis, bacterial or parasitic infections.

The toxicity of cacodylic acid in humans is not known but workers in the Ansul Chemical Company plant have had repeated exposures over long periods of time. Ansul says that their experience confirms the observations on rats that the toxicity of these compounds is "relatively low" (Stevens, 1966).

Acute oral toxicity studies of cacodylic acid in rats have shown that the LD_{50} for male rats (1,400 mg/kg) is about the same as the LD_{50} for the female rats (1,280 mg/kg). A combination of these data provides a figure of 1,350 mg/kg with 95% confidence limits falling between 1,110 and 1,640 mg/kg (Ansul Chemical Company, 1967). It should be noted that this toxicological study was performed with Ansul Chemical Company's commercial product containing 61.29% of cacodylic acid, 33% sodium chloride and 0.09% trivalent arsenic. This product appears to be identical to Ansar 138 (Ansul Chemical Company, 1964). In Table VI-1 will be found a listing of the acute toxicities of several commercial formulations of cacodylic acid herbicide products. The results bear no simple relationship to the amount of cacodylic acid each contains. Meliere (1959) reports that acute oral toxicity of pure cacodylic acid to male rats is greater than 184 mg/kg and that no deaths occurred at this dose level.

Albino rabbits were used in a study of the dermal irritation properties of cacodylic acid (77%). In this study the acid was applied to both intact and abraded skin in the amount of 0.5 ml or 0.5 g/area and covered with gauze and rubberized cloth for 24 hr and 72 hr. By this test the cacodylic acid was found to be essentially nonirritating to the skin. The same result was obtained when a commercial formulation containing 61.29% cacodylic acid was used (Ansul Chemical Company, 1967).

Eye irritation tests of cacodylic acid, 20% w/v solution in water, were made by application to the eyes of New Zealand White rabbits and observing the cornea, the iris and the conjunctivae for a total of 72 hr. There was no opacity of the lens and the mild irritation which developed quickly cleared with no permanent damage to the eye. It was judged that this material would be essentially nonirritating if accidently splashed into the eye (Ansul Chemical Company, 1967).

TABLE VI-1

ACUTE ORAL TOXICITY OF CACODYLIC ACID IN RATS

Cacodylic Acid Formulations*	Percentage Active	How Used	Species	Sex	LD_{50} (mg/kg) (Conf. Limits)	Ref.
Lots 22-33	77	20% in H_2O	Rats	-	700	a/
AR-3214	61.29	20% in H_2O	Rats	M	1400 (1150-1710)	a/
AR-3214	61.29	20% in H_2O	Rats	F	1280 (930-1750)	a/
AR-3214	61.29	20% in H_2O	Rats	M+F	1350 (1110-1640)	a/
Ansar 560 Herbicide	25.1	Undiluted	Rats	M+F	2600 (2100-3200)	a/
Silvisar-510 Tree Killer 584-47-1	49.5	10% in H_2O	Rats	-	644 S.D. ± 126	a/
607-23-1 (contains 2.1% trivalent arsenic)	41.2	10% in H_2O	Rats	-	443 S.D. ± 45	a/
Phytar 560 acid, 3.9% Sodium salt, 22.6% (has surfactant)	23.4	in H_2O	Holstein Dairy Cows	F	1700	b/

* Ansul Chemical Company, Marionette, Wisconsin.
a/ Toxicological data - Methanearsonic acid and dimethylarsinic acid, Ansul Chemical Company, Marinette, Wisconsin.
b/ Toxicity of "PHYTAR" 560 Herbicide to Livestock, Ansul Chemical Company, Chem. Div. Bulletin, Marinette, Wisconsin.

The subacute toxicity of cacodylic acid in weanling male Sprague-Dawley rats was determined by means of a 90-day feeding test in which 10, 20 and 40% of the LD_{50} dose of cacodylic acid was mixed with the feed. In this case the amounts of material actually incorporated into the feed were 0.07, 0.14 and 0.28% cacodylic acid. Records were kept of the total food consumed and the body weights of the rats during the experiment. At the highest level (0.28%) 2 of the 10 animals died and the weight gain was less than half that of the control. These animals exhibited a reduction of spermatogenesis and early atrophic changes within some seminiferous tubules. One animal showed some early degeneration of the hepatic cells. The rats receiving the 0.14% cacodylic acid in their diets gained a little less weight than the controls but showed no gross pathological conditions (Ansul Chemical Company , 1967).

A 60-day feeding test on the metabolism of cacodylic acid (Ansar 138) in dairy cows was conducted (Ansul Chemical Company, 1964 and 1967) . Two holstein milk cows were fed a diet of ground barley, wheat bran and cotton-seed meal containing 10 ppm of cacodylic acid. This resulted in a daily intake of 24.5 mg/kg/cow. In another group of cows an equal weight of arsinic acid was fed to the cows. The milk from both groups of these cows was analyzed and found to contain no arsenic during the entire test period. The excretion of arsenic is primarily by way of the urine and a balance between intake and output is present after 30 days of feeding. At the end of the experiment, the cows were sacrificed and 10 tissues and bone were analyzed for arsenic. It was concluded that no tissues stored arsenic compounds on a cumulative basis even though fractional parts per million of arsenic were detected in the liver, spleen and pancreas. The differences in arsenic content of the organs from the cows fed cacodylic acid and those fed arsenic acid were insignificant (Ansul Chemical Company, 1967 and Peoples, 1964).

K. H. Oliver (1966) has done an ecological study of the effect of cacodylic acid spraying on five ecotones including the sandhill community, the hammock, the grassland, the pond, and the stream. Unfortunately, his observations on the effect of cacodylic acid on fish were done in the laboratory rather than in the field. In these studies he exposed Gambusia addinis (mosquito fish), Notropis maculatus (tail-light shiner) and Micropterus salmoides (largemouth black bass) to concentrations ranging from 100 to 10,000 ppm of cacodylic acid for periods up to 72 hr. All three species of fish survived the 100 ppm level for this period. Although there were some deaths of the Gambusia at lower doses, 12 out of 20 survived 631 ppm for 72 hr. Five out of 10 of the Notropis survived exposure to 631 ppm for 72 hr.

In a similar experiment with tadpoles (Oliver, 1966) it was shown that tadpoles (Bufo terrestris) survived the 100 ppm level for 48 hr and all died at this time period at 1,000 ppm. Oliver suggests that since the LD_{50} of rabbits is 250 mg/kg that they might be killed by eating vegetation which had been sprayed but no evidence of such poisoning was presented.

In Section C of this chapter (p. 198), we state that the effect of herbicides on the microorganisms in the soil could be important in the maintenance of soil fertility, the growth of leguminous crops, and perhaps the inhibition of pathogenic organisms in the soil. Zabel and O'Neil (1957) have reported on the relative toxicity of 44 arsenicals against common slime-forming microorganisms by a petri plate method. The test organisms were two bacteria, Aerobacter aerogenes and Bacillus mycoides and two fungi, Aspergillus niger and Penicillium expansum. Methylarsonic acid and cacodylic acid were inhibitory to these organisms at concentrations of 2,000 ppm. Arsenic trioxide (100 to 240 ppm) and arsenic pentoxide (270 and 620 ppm) both inhibited bacteria but were relatively ineffective inhibitors of the fungi. It was concluded that the arsenic trioxide was the better bacteriostatic agent.

Various organizations in the beekeeping industry are much concerned about the possible hazard resulting from the use of pesticides particularly with their use on those crops which form the basis of the bee forage. The concern stems from the possible presence of toxic material in the bloom which may kill or incapacitate the bee and also the elimination of many of the wild flowers which are also a source of food. The chlorinated insecticides have given much bee toxicity in both laboratory and field tests while most of the herbicides have not. The arsenicals, dinitro (especially DNOSBP*) and endothall weedicides have been shown to be highly toxic to bees (Washington State University, 1965). Bohmont (1967) has looked over the literature on the toxicity of herbicides and is also concerned about the arsenicals and dinitro compounds; however, he states, "the current aquatic weed control treatments are probably not hazardous to honey bees collecting water from irrigation ditches."

Bark beetles have been inhibited by cacodylic acid. Chansler and Pierce (1966) did a careful study on the effect of cacodylic acid solution injections into trees possessing large infestations of bark beetles. The solutions contained either 3.25 or 5.7 lb. of cacodylic acid per gallon and about 150 ml/tree was injected into the sap of each tree. The trees died but so did 84 to 99% of the bark beetles; the author suggests this procedure as a possible method of controlling this beetle.

Bio-assay screening tests on the toxicity of cacodylic acid (65% active) were conducted by the Bureau of Commercial Fisheries Biological Laboratories (Bureau of Commercial Fisheries, 1966). They showed that cacodylic acid at 40 ppm has no effect in 48 hr. on pink shrimp (Penaeus duorarum), eastern oyster (Crassostrea virginica) or longnose killifish (Fundulus similis).

Arsenicals, particularly the trivalent forms of arsenic, have long been considered as either carcinogens or possibly as co-carcinogens. In either case there is reason to be wary of the widespread distribution of these

* Dinitro-o-(sec-butyl)-phenol.

materials until evidence of their long-term safety under the conditions of use has been obtained. S. S. Pinto and B. M. Bennett (1963) believe that it is a mistake to make blanket condemnations of the use of arsenic without first looking at the data. He has reviewed the early literature on human tumors from arsenic and also the recent opinions and interpretations of these early papers. There is reason to believe that the "arsenic tumors" observed in 1820 may have been due to other causes such as selenium poisoning. He reviewed the medical histories and causes of death for the long-term employees of a copper smelting company producing arsenic trioxide. He showed that the workers do excrete high levels of arsenic but that their incidence of cancer is no greater than for other persons in the State of Washington. He concluded that there is no evidence that exposure of these workers to arsenic trioxide is a cause of systemic cancer in humans. In a sense this amounts to the use of human guinea pigs for establishing the lack of carcinogenicity of arsenic trioxide.

Peoples (1964) and Ehman (1964) are individuals who believe that arsenicals as a class are much maligned without due cause. They point out that no arsenic is excreted in the milk of a cow whether the arsenic administered is in the form of arsenic acid, sodium arsenite, or cacodylic acid. They conclude that the metabolism of arsenic in the rat is unique and suggest that we should revise our present thinking of arsenic as a cumulative poison. "The evidence linking arsenicals to cancer in industrial applications is almost nonexistent,"(Ehman , 1964).

There is, however, evidence that cacodylic acid is a mitotic poison in mammalian organisms since King and Ludford (1960) have found that injections into mice produced "profound disturbances of cell division" and it "stimulated mitosis in cells of the crypts of Lieberkuehn" and of transplanted tumors.

That cacodylic acid is considered to be a teratogenic agent producing abnormalities during embryonic development is shown by the fact that there are several references to this type of action although only two examples are quoted. Salzgeber (1955) observed teratogenic effects in 10-day chick embryo genital organs cultured in vitro and has reported that the greatest damage is to the cortical region. Rostand (1950) has treated tadpoles of Rana temporia with solutions of cacodylic acid for three weeks when the hind legs were in the process of development and abnormalities were observed at 0.01% of sodium cacodylate. (This concentration is 100 ppm and is equivalent to 270 lb/acre ft of water)

In the examination of the potential toxicity hazard for this compound, we were particularly impressed by the low oral toxicity. In view of the absence of long-term feeding studies or of reproduction studies, we feel that these should be undertaken soon. Additional research into cacodylic acids' possible teratogenic acitivity and carcinogenic activity should be undertaken.

According to Dr. Warren Zick (1967) of the Ansul Chemical Company, cacodylic acid is applied at the rate of 0.5 lb/acre for the destruction of rice crops. The presence of toxic residues on rice from sprayed fields appears not to be a problem since no rice develops in these fields.

Dalapon

2,2-Dichloropropionic acid is better known as dalapon and it is usually formulated as the sodium salt which contains about 85% active ingredient or 74% based upon acid equivalent. It is used principally for the control of grasses but it is also effective against jack and white pine, phragmites, rushes and white cedar. It is frequently used in combination with a broadleaf killer such as 2,4-D. According to toxicity data supplied by the Dow Chemical Company (Herbicide Handbook WSA, 1967) the acute oral toxicity of dalapon is as follows:

Rat (M)	9,330 mg/kg
Rat (F)	7,570 mg/kg
Mouse (F)	> 4,600 mg/kg
Guinea Pig (F)	3,860 mg/kg
Rabbit (F)	3,860 mg/kg
Chick (M + F)	5,660 mg/kg

Studies on the subacute and chronic toxicities of dalapon have been conducted. A heifer calf was fed 1,000 mg/kg/day for 10 days; there were general nonspecific symptoms but the calf recovered after cessation of the treatment. A bull calf was treated with 1,000 mg/kg for 10 days with no apparent symptoms; autopsy of this calf showed possible slight kidney involvement. Administration of 50 mg/kg of dalapon to dogs for five days a week was continued for 80 days although near the end of the experiment the level was increased to 1,000 mg/kg; vomiting at the high doses was the only adverse effect noted.

Palmer and Radeleff (1964) found that the sodium salt of dalapon was not toxic to sheep when administered at the rate of 100 mg/kg for a total of 481 daily doses. One sheep was given 10 daily doses of 500 mg/kg without ill effect. Cattle were treated with 10 daily doses of 250 or 500 mg/kg of the sodium salt of dalapon; there was no effect at the lower level but there was swelling of the parotid at the high level.

Hymas (1958) reported on the acute oral toxicity of dalapon (sodium salt) to a variety of animals including dogs and cattle. The LD_{50} for dogs is greater than 1,000 mg/kg and that for cattle is in excess of 4,000 mg/kg.

One cow was given 1,000 mg/kg for 10 days and moderate toxic symptoms were observed but a steer was fed at this same level and no toxic effects were seen.

In a one-year feeding test dogs were fed either 50 ppm or 100 ppm of dalapon; at the higher dose level there was a slight increase in kidney weight but at the 50 mg/kg level there was no effect. In a two-year feeding test with rats at 5, 15 and 50 mg/kg levels, there was slight average kidney weight increase at the highest level and no effect at the lower levels. At the highest dose levels, 10 to 30 ppm of dalapon was found in the liver and kidney and 20 ppm in the milk. Reproduction and lactation studies in rats were carried through three generations while feeding diets containing 300 and 3,000 ppm of dalapon (i.e., about 15 and 150 mg/kg); no abnormal effects were reported (Paynter et al., 1960).

Andersson et al.(1962) conducted an eight-week feeding test starting with day-old chicks and feeding them dalapon at 100, 1,000 and 10,000 ppm in the feed. He concluded that there were no signs of toxicity at the 100 ppm level and therefore the hazard to livestock and wildlife resulting from the use of dalapon at 10 ppm in aquatic weed control would probably not be great.

Concentrated solutions of dalapon are mild skin irritants and may produce a mild burn if there is long or repeated contact. It is not absorbed through the skin in toxic amounts. Eye irritation with transient corneal injury may occur but healing should be complete in several days (Herbicide Handbook WSA, 1967).

Experiments on toxicity of dalapon to fish have been conducted by C. E. Bond et al.(1959). The median 48-hr. tolerance limit for Coho salmon is 340 ppm. Largemouth bass survived 1,000 ppm for 48 hr in an aquarium but all died at this level in a flowing stream test. Goldfish survived 10 ppm for 48 hr, bluegills survived 80 ppm for 108 hr and emerald shiners survived 3,000 ppm for 72 hr (Lawrence, 1962). Surber and Pickering (1962) report that the median tolerated limit for a 96-hr exposure of dalapon to bluegills and fathead minnows are 290 to 440 and 290 to 390 ppm, respectively.

Dalapon appears to have little inhibitory effect on microorganisms and the fixation of nitrogen by Azotobacter since Magee and Colmer (1955) have reported that it takes 7,000 ppm to inhibit this organism. McCalla et al. (1962) reported on a field study in which dalapon had been applied to the soil for four consecutive years; they found that there was no measurable effect on soil pH, amount of organic matter, soil bulk density, total numbers of bacteria or actinomycetes. However, there was a reduction in the numbers of nematodes and the nitrification of the top 1 inch of soil was retarded.

In the summary it appears that the use of dalapon presents minimal toxicity hazards to fish and wildlife so long as it is applied according to the label instructions.

Diquat

6,7-Dihydropyrido(1,2-α:2'1'-c)pyrazidinium salt, diquat, is registered as a noncropland weed killer of special value in the control of aquatic weeds and as a preharvest top killer or desiccant of seed crops. The acute oral toxicity in rats is LD_{50} = 157 mg/kg (USDA Agriculture Handbook No. 332, 1967). On the other hand, the Herbicide Handbook WSA (1967) in reporting data obtained from the Chevron Chemical Company and the ICI Plant Protection, Ltd. England, report the acute oral LD_{50} in rats to be 400 to 440 mg/kg (i.e., about one-third as toxic). Diquat is much more toxic when given by subcutaneous injection and the LD_{50} for rats is 20 mg/kg with death occurring in five to seven days according to a data sheet of Plant Protection, Ltd. and cited by Dalgaard-Mikkelsen and Poulsen (1962). Chronic toxicity tests in rats were performed in which 25 mg/kg were fed in the diet over a period of 16 months during which time there was no interference with the growth and no toxic symptoms were observed (Herbicide Handbook WSA, 1967). Intraperitoneal injections of 500 mg/kg to rats produced cyanosis and convulsions culminating in death after 2 hr. Subcutaneous injection on 1 mg/kg into rats daily for 21 days caused no sign of toxicity. Similarly, feeding experiments to rats for over 14 months with 500 ppm in the diet disclosed no carcinogenic or toxic action. Following oral administration of C^{14} labeled diquat, 90 to 97% of the radioactivity was recovered in the feces in 48 hr. The difference in toxicity between the injection and the oral dosage suggests that adsorption from the gut is very poor.

Skin tests in rabbits showed that application of diquat at the rate of 500 mg/kg produced no toxic reactions. Eye irritation tests conducted with 10% solution of diquat produced no eye damage.

The tissue and milk residues arising from the ingestion of single doses of C^{14} labeled diquat by dairy cattle has been reported by Stevens and Walley (1966). Diquat dibromide was given to cows at 5 to 20 mg/kg and the milk was tested for radioactivity for seven days. Less than 0.02% of the radioactivity appeared in the milk and they concluded that this amount of diquat would be safe in humans. Very little of the radioactivity appeared in the urine and most of it appeared in the feces.

Surber and Pickering (1962) have examined the toxicities of fish to diquat and have concluded that bluegills, largemouth bass and fathead minnows, respectively, can tolerate 7.2, 7.8 and 14 ppmw/v for 96 hr in soft water and two to ten times these quantities in hard water. Since weed control in ponds can be attained at levels of 1 to 3.0 ppm, these investigators conclude that diquat appears to have an adequate safety margin to permit its use in aquatic weed control. Cope (1966) has reported on the concentration of insecticides and herbicides in fish tissues when they are exposed to known concentrations for a 30-day exposure. Rainbow trout were kept in water containing 1 ppm of diquat; after the exposure period the residues in the whole fish amounted to 0.09 ppm indicating that this fish does not have the ability to concentrate diquat. Cope also reported that the concentration of diquat producing toxicity in 50% of the rainbow trout in 48 hr is 20 ppm. Although direct toxicity to fish is not considered to be a problem, diquat can kill sufficient pond vegetation to cause severe oxygen deficiencies and death of fish (Johnson, 1965). Bond (1959) estimates the median tolerance limits for 24- and 48-hr exposures of chinook salmon to be 29.5 and 28.5 ppm of diquat. All chinook salmon exposed to 100 ppm of diquat died within 2 hr.

Beasley et al. (1965) gave goldfish intraperitoneal injections of C^{14} labeled diquat and later measured the distribution of the radioactivity in the various tissues of the fish. They concluded that diquat accumulates (to a limited extent) in the gastro-intestinal tract whether the diquat is given by injection or whether the fish is allowed to swim in water containing it.

G. R. Fish (1966) in his studies on the effects of 0.5 ppm of diquat on the control of aquatic weeds in Lake Rotoiti, New Zealand, reported that due to the cool temperature of the water the killing of the heavy infestation of *Lagarosiphon major* was slow but effective and that there was no decrease in the lake oxygen due to the increase in ciliates and photosynthetic algae (mostly *Staurastrum*, *Anabaena* and green flagellates).

Crosby and Tucker (1966) have studied the effects of paraquat and diquat on the fish food chain and have concluded that diquat (7.1 ppm) and paraquat (11.0 ppm) immobilize and/or kill *Daphnia magna*. They conclude that careful use of these herbicides at 3 ppm or below for aquatic weed control will probably not seriously affect this important link in the food chain. Tatum and Blackburn (1967) conducted a study on the effect of 0.5 ppm of diquat on the existing plankton and benthic organisms on two farm ponds at Ft. Lauderdale, Florida. They found that there was some adverse effect on the plankton but that it recovered quickly; the decaying vegetation appeared to benefit benthic organisms. The effect of the diquat on the *Chironomids* was inconclusive since the results in different ponds were different.

Blackburn and Weldon (1963) after a three year testing program report that diquat applied to small ponds at 0.5 ppmw appears to have little effect on the natural fauna and plankton present. Also diquat at 2.5 ppmw showed no toxicity to fish.

Even though diquat must be considered as a "moderately toxic" substance we conclude that its use in accordance with label instructions will have little toxicity effect except upon the vegetation.

Diuron

3-(3,4-Dichlorophenyl)-1,1-dimethylurea or diuron is closely related to monuron and is used widely for soil sterilization and as a pre-emergence herbicide. The acute oral toxicity to rats (LD_{50}) is 3,400 mg/kg. In short term feeding tests on rats, 5,000 ppm of diuron in the diet suppressed growth and resulted in pathology of the spleen and a slight lowering of the red blood cell counts (George, 1960). At 50 ppm, diuron was well tolerated by the rats. Application of 50% aqueous pastes of diuron to guinea pig skin was nonirritating to intact skin and moderately irritating to broken skin. Diuron did not produce any allergic skin reactions in laboratory animals nor have they been observed in experimental subjects or factory employees working with these compounds (Dalgaard Mikkelsen and Poulsen, 1962).

Palmer (1964) reported that a single oral dose of 250 mg/kg of diuron in a sheep produced tympanites accompanied by incoordination and dyspnea followed by recovery. A sheep given two daily doses of 100 mg/kg each was severely poisoned and lost 15.5 lb. before he recovered. A sheep given 11 daily doses of diuron at 25 mg/kg was unaffected and even gained 3 lb. during the test.

From Table VI-2 it may be seen that diuron does have a toxic effect on oysters at 1.8 ppm and also on juvenile fish at 6.3 ppm; perhaps the greatest change is the 87% decrease in productivity (carbon fixation) of natural phytoplankton communities during a 4-hr. exposure to 1.0 ppm of diuron. Largemouth bass were able to tolerate 42 ppm of diuron while the median tolerance limit for Coho salmon for a 48-hr. exposure was 16 ppm. Bluegills were quite resistant but white crappies (Pomoxis annularis) were killed by concentrations as low as 6 ppm of diuron (Bond, 1959). Treatment of ponds with 5 and 10 ppm of diuron resulted in the death of bluegills and largemouth bass. The 10 ppm treatment apparently eradicated all fish and bullfrog tadpoles from the pond--probably due to a lack of dissolved oxygen resulting from the decay of killed plants. Rainbow trout were able to survive 60 ppm of diuron for 96 hr (Bond, 1959).

Diuron appears to be relatively nontoxic and no direct or indirect toxicity is anticipated from its use even at levels up to 80 lb/acre.

TABLE VI-2

TOXICITY OF HERBICIDES TO ESTUARINE ORGANISMS

Herbicide	Oysters 96-hr EC_{50}[a/] ppm(mg/liter)	Shrimp 48-hr EC_{50}[b/] ppm(mg/liter)	Fish 48-hr LC_{50}[c/] ppm(mg/liter)	Phytoplankton % Decrease[d/] at 1.0 ppm
Phenoxy Acids and Derivatives				
2,4-D, acid[e/]	ne at 2.0	10% at 2.0(B)[f/]	ne at 50 [g/](S)[h/]	0
2,4-D, butoxy ethanol ester	3.75	ne at 1.0 (P)	5.0[g/](K)	16
2,4-D, dimethylamine salt	ne at 2.0	10% at 2.0(B)	ne at 15[g/](K)	0
2,4-D, ethyl hexyl ester	38% at 5.0	10% at 2.0(B)	ne at 10[g/](M)	49
2,4-D.propylene glycol butyl ether ester	39% at 1.0	ne at 1.0 (P)	4.5[g/] (K)	44
2,4,5-T, acid	ne at 2.0	ne at 1.0(B)	ne at 50[g/](M)	0
2,4,5-T, polyglycol butyl ether ester	0.14	20% at 1.0(B)	0.32(S)	89
Silvex, polyglycol butyl ether ester	23% at 1.0	0.24(B)	0.36(S)	78
Urea Compounds				
Diuron	1.8	ne at 1.0(P)	6.3[g/](M)	87
Fenuron	ne at 2.0	10% at 1.0(B)	ne at 1.0(S)	41
Monuron	12% at 2.0	ne at 1.0(W)	16.3[g/](M)	94
Triazine Derivatives				
Atrazine	ne at 1.0	30% at 1.0(B)	ne at 1.0(S)	--
Miscellaneous Herbicides and Formulations				
Dalapon, sodium salt	ne at 1.0	40% at 1.0(B)	ne at 1.0(K)	0
Diquat	ne at 1.0	ne at 1.0(W)	ne at 1.0(K)	45
Estron 99 (2,4-D formulation)	0.055	0.55(B)	1.5[g/](S)	--
Paraquat	ne at 1.0	ne at 1.0(P)	ne at 1.0(K)	53
Tordon 101	ne at 1.0	ne at 1.0(B)	ne at 1.0(M)	0
Veon 245 (2,4,5-T formulation)	ne at 1.0	ne at 1.0(B)	ne at 1.0(S)	0

a/ 96-hr EC_{50} = Concentration of herbicide in sea water causing a 50% decrease in oyster shell growth.
b/ 48-hr EC_{50} = Concentration of herbicide in sea water causing mortality or paralysis to 50% of adult shrimp tested.
c/ 48-hr LC_{50} = Concentration of herbicide in sea water causing 50% mortality to juvenile fish.
d/ Percent decrease = Percent decrease in productivity (carbon fixation) of natural phytoplankton communities during a 4-hr exposure to 1.0 ppm of the indicated herbicide.
e/ ne = No effect.
f/ B = brown shrimp, Penaeus aztecus; P = pink shrimp, Penaeus duorarum; W = white shrimp, Penaeus setiferus.
g/ Results obtained from standing water tests.
h/ S = spot. Leiostomus xanthurus; K = longnose killifish, Fundulus similis; M = mullet, Mugil cephalus.

Source: P. A. Butler, "Effects of herbicides on estuarine fauna," Southern Weed Conf. Proc., 18, p. 576. (1965).

Endothall

3,6-Endoxohexahydrophthalic acid or endothall consists of a mixture of three isomers of which the exo-cis isomer shows the greatest biological activity. It is somewhat selective and is often combined with 2,4-D to obtain complete vegetation control. Some of the weeds it controls are burreed, coontail, horned pondweed, watermilfoil and pondweeds (Potamogeton spp.) (Dunham, 1965). Data on the toxicity of endothall have been supplied by the Pennsalt Chemical Corporation (Herbicide Handbook WSA, 1967). The acute oral toxicity in rats for the technical grade endothall acid is 38 to 51 mg/kg, while the LD_{50} for the solution of the sodium salt containing 19.2% acid equivalent is 182 - 197 mg/kg. The amine salt formulation containing 66.7% acid equivalent has an LD_{50} of 206 mg/kg. The lethal dose by intravenous injection in rabbits and dogs is of the order of 5 to 10 mg/kg (Goldstein, 1952). Shortly after administration, scratching of the nose was observed and in the dogs vomiting and retching lasted 2 hr. The observation that there is a long latency for the toxic manifestations suggest that there is a metabolite involved in the process (Srensek and Woodard, 1951). Applications of 10 and 20% solutions of endothall sodium to rabbit skin resulted in erosion which developed into necrosis, in some cases leading to death due to dermal absorption (Goldstein, 1952).

Chronic toxicity testing included two-year feeding studies with both rats and dogs. The rats are more sensitive to endothall than are the dogs but the "no effect" level in the feed was 300 ppm for both animals. The manufacturer suggests that this amounts to a safety factor of about 150 calculated on the possible daily intake by humans and therefore use of endothall does not constitute a hazard to public health.

Surber and Pickering (1962) report that endothall is not very hazardous to fish. They determined the maximum tolerated limit for bluegills, largemouth bass and fathead minnows in both hard and soft water and that all fish survived 96 hr. at 180 ppm; the fathead minnows in hard water survived 610 ppm for this period. The toxicity of endothall to lake Emerald Shiners (Notropis atherinoides) has been reported by Swabey and Schenk (1963). In their studies they found the median tolerated limit for the cocoamine salt of endothall (the form most toxic to fish) was 0.08 ppm on the basis of a 96-hr exposure (see Table VI-11 for a comparison with other herbicides).

Walker (1962) has investigated the effect of endothall di-N,N'-dimethylcocoamine salt on "bottom organisms." He reports that concentrations greater than 1 ppm killed all of the bottom organisms; at concentrations of 0.1 to 0.6 ppm the organisms will concentrate the endothall compound (approximately a 200-fold concentration in three weeks). Crosby and Tucker (1966) have reported that endothall at 3 ppm, about the upper limit used in aquatic weed control, will have little influence of Daphnia magna since it can tolerate up to 46 ppm.

The hazardous nature of this herbicide is shown by the instructions issued by the Pesticide Regulation Branch which states: "Do not use fish from treated water for food or feed within three days of treatment. Do not use treated water for irrigation, watering livestock, domestic purposes or agricultural spraying within seven days of treatment." (Quoted by George, 1960).

However, the hazard to fish does not appear to be great provided the proper formulation is employed. The direct toxic effect on humans during application for aquatic weed control is expected to be minimal.

Methanearsonic Acid

Under this heading we are describing the toxicity of methanearsonic acid (MAA), and its mono and disodium salts which are better known as MSMA and DSMA. These materials are used as post-emergence herbicides for the control of certain grasses and are used alone in solutions or in combination with a surface active agent. Methanearsonic acid in its various form is considered as more a selective phytotoxic compound than cacodylic acid, and less toxic to animals than sodium arsenite (Stevens, 1966).

Meliere (1959) has measured the acute oral toxicity of methanearsonic acid in male mice and has found that the LD_{20} is 185 mg/kg. He found the LD_{50} of the disodium methanearsonic acid to be greater than 245 mg/kg. In data supplied by the manufacturers of these materials and listed in the Suggested Guide for Weed Control (USDA, Agricultural Handbook 332, 1967) the acute oral toxicity for rats of the monosodium and the disodium methanearsonic acids is 700 mg/kg for MSMA and 800 to 2,800 for DSMA. These figures are slightly at variance with the toxicity data supplied by the Ansul Chemical Company (1967). For the purified methanearsonic acid (92.8%) they report an approximate LD_{50} of 1,400 mg/kg in rats. For one sample of their commercial formulation (Ansar 184) which contained 63.9% of disodium methanearsonate and 1.53% of the monosodium acid methanearsonate (MSMA) the acute oral toxicity in rats was found to be LD_{50} 2,800 mg/kg with 95% confidence limits falling between 2,220 and 3,700 mg/kg. For their commercial formulation known as Ansar 170 and containing predominently the monosodium salt (MSMA, 51.55% and the free acid, 0.95%) the acute oral toxicity in rats was LD_{50} 1,800 mg/kg with the 95% confidence limits falling between 1,500 and 2,200 mg/kg. It is clear that methanearsonic acid and its salts MSMA and DSMA have about the same acute oral toxicity in rats as cacodylic acid and are less toxic to rats and mice than is sodium arsenite. It also appears that the disodium methanearsonate (DSMA) is much less toxic than the parent acid and the difference is greater than might be predicted on the basis of their arsenic content. A comparison of the acute oral toxicity of different methanearsonic acid formulations is shown in Table VI-3; it will be noted that cows are more susceptible than rats and mice.

The skin irritation tests with methanearsonic acid (Ansul Chemical Company, 1967) were conducted in the usual manner using the intact skin of three rabbits and the abraded skin of three rabbits. After 24- and 72-hr exposure to this herbicide it was found to produce a slight edema and to be mildly irritating. The reactions observed in the highest doses prior to death included general inactivity, loss of appetite, mild sedation, dyspnea and muscular weakness. At 1,400 mg/kg the animals which succumbed lived about 24 hr following administration.

Methanearsonic acid, its mono- and disodium salt (i.e., MSMA and DSMA) all contain carbon to arsenic linkages which may account for their reduced animal toxicities. On the basis of available information, the toxicity hazard resulting from the use of these substances does not appear great but more toxicological data are needed.

Monuron

3-(p-Chlorophenyl)-1,1-dimethylurea otherwise known as monuron belongs to the class known as the phenylurea herbicides and is extensively used as a soil sterilant. It is somewhat more effective on grasses than nongrasses but is more effective than sodium chlorate (Dunham, 1965) and is used in both crop and noncroplands. The acute oral toxicity to rats is 3,600 mg/kg. The acute oral toxicity for rabbits is 1,500 mg/kg; for guinea pigs 670 mg/kg. In short term feeding tests monuron fed at 5,000 ppm suppressed growth and produced pathology of the spleen and lowered the red blood cell counts. Two-year feeding studies in rats and one year in dogs at 250 and 500 ppm shows that the "no effect" level for monuron lies between these two dose levels (Herbicide Handbook WSA, 1967). In the two-year feeding test rats were fed monuron at 25, 250 and 2,500 ppm and no effect was noted on survival or frequency of tumors as compared with the control group and in the colony of normal rats. The conclusion was drawn that there was "no indication that monuron is carcinogenic" (Hodge et al., 1958). Skin tests with both intact and abraded guinea pig skin showed that there was no irritation or sign of sensitization.

Palmer (1964) fed a sheep two daily doses of monuron at 250 mg/kg and the sheep became weak and bloated and,since the sheep did not appear to improve it was killed and necropsied; the symptoms were inflammation of the liver and kidneys, numerous petechiae in the small intestinal mucosa and congestion of the meninges. Another sheep was given four daily doses of 100 mg/kg of monuron during which time it lost 16 lb. and treatment was stopped. At a daily dose of 25 mg/kg, 11 daily doses of monuron in sheep produced no apparent

TABLE VI-3

ACUTE ORAL TOXICITY OF METHANE ARSONIC ACID FORMULATIONS IN RATS

Methane Arsonic Acid (MAA) Formulation	Percentage Active	How Used	Species	Sex	LD_{50} (mg/kg) (Conf. Limits)	Ref.
Commercially Pure MAA	92.8	in H_2O	Rats	-	1400	a/
Ansar 184 Herbicide Monosodium Salt, 1.53% Disodium Salt, 63.92% Total DSMA equivalent 65.66%	65.66	in H_2O	Rats	-	2800 (2200-3700)	a/
Ansar 170 MA, 0.95% Monosodium Salt, 51.55% Total MSMA equivalent 52.65	52.65	in H_2O	Rats	-	1800 (1500-2200)	a/
Ansar 529 (has surfactant) Monosodium Salt, 34.69% Disodium Salt, 0.59% Total MSMA equivalent 35.21%	35.21	Undiluted	Rats	-	1800 (1600-2000)	a/
Ansar 529 (has surfactant) Monosodium Salt	34.8	in H_2O	Holstein Dairy Cows	F	250	b/
Ansar 170 Monosodium Salt	51.3	in H_2O	Holstein Dairy Cows	F	230	b/

a/ Toxicological data - methanearsonic acid and dimethylarsinic acid, Ansul Chemical Company, Marinette, Wisconsin.

b/ Toxicity of "ANSAR" 529 Herbicide to Livestock, Ansul Chemical Company, Chem. Div. Bulletin, Marinette, Wisconsin.

effect except for a one-half pound loss in weight. Lawrence (1964) has summarized the 48-hr effect of monuron on fish; Coho salmon survived 110 ppm; channel catfish survived 39.8 ppm; largemouth bass, smallmouth bass, bluegill, green sunfish, brown sunfish, carp, fathead minnow, Sacramento squawfish and golden shiner all survived 32 ppm; frogs and tadpoles survived 10 ppm. However, in a California pond, 0.9 ppm killed rainbow trout.

Crosby and Tucker (1966) have reported that the median immobilization concentration for 50% of the Daphnia magna (IC_{50}) is 106 ppm for monuron or about 50 times the concentration recommended for field use. Walker (1962) has reported on the effect of 1 to 2 ppm monuron on bottom organisms and has found that both the weight and total numbers of organisms decrease during a 12 week period.

From our examination of the toxicity data we do not anticipate direct acute toxicity to man or animals when monuron is used in accordance with the label recommendations. The effect on fish should be low since neither direct nor indirect toxicity is expected as the result of the use of this herbicide.

Paraquat

Paraquat, also known as 1,1'-dimethyl-4,4'-bipyridinium salt or methyl viologen, is closely related to diquat both chemically and in the mechanism of its phytotoxicity. These two compounds are readily converted into free radicals when exposed to sunlight and these free radicals are thought to be the form of the chemical which interferes with photosynthesis (Funderburk and Lawrence, 1964, Slade, 1966, and Boon, 1964). Leaves of diquat- or paraquat-treated plants retain their shape and color until they are exposed to light and at that time they turn black. Paraquat is used principally in brush control along rights-of-way and in the killing of aquatic weeds.

Paraquat is highly toxic to man and there have been several reported fatalities. Bullivant (1966) reported that up to July 1964, one case of paraquat poisoning had occurred in a child in Ireland. He described two additional cases in men in 1966. The first was a 28-year old man who drank a half glass of 20% paraquat solution. The second case was a 23-year old man who drank one mouthful and vomited immediately. In both cases there were signs of hepatorenal damage and the men died of respiratory failure. A third man gave himself approximately a 1 ml injection of a 20% solution of paraquat. He died 14 days later of respiratory failure. According to Ackerman and Regato(1954),the histological picture of the lungs of all of these individuals is that of pulmonary proliferative process which resembles the effects noted when carcinogenic hydrocarbons are given to laboratory animals. Almog and Tal (1967) who described this last poisoning case urged that carcinogenicity studies should be conducted with paraquat. The estimated fatal dos in humans is estimated to be 4 mg/kg.

Bullivant (1966) uses these words to describe the pathological changes in humans following paraquat ingestion, "Much of the lungs were air-less owing to fibroblastic proliferation in the alveolar walls and elsewhere... (this) represents an unusual pulmonary reaction to a single dose of a toxic substance, which, while not persisting very long in the body, initiates during its stay progressive changes ultimately leading to death."

Daniel and Gage (1966) in their work with laboratory animals report that the administration of C^{14} labeled paraquat has shown that 96% of the paraquat is eliminated in the urine within three days.

Clark et al. (1966) have studied the acute toxicity of paraquat in experimental animals and the data are shown below:

Animal Toxicity of Paraquat

Species	No. of Animals	Route	mg/kg LD_{50} (Conf. Limits)
Rats (F)	6	Oral	112 (104 to 122)
Rats (F)	10	Oral	150 (139 to 162)
Rats (F)	6	Oral	141 (140 to 142)
Rats (F)	6	I.P.	19 (16 to 21)
Rats (F)	6	I.P.	16 (14 to 19)
Guinea Pigs	3	I.P.	3
Rhode Island Hens	5	Oral	262 (200 to 346)
Cats (F)	5	Oral	35 (27 to 46)

The acute oral toxicity in rats given in the Agricultural Handbook 332 (1967) is 157 mg/kg and is in line with the data presented above. Studies on the absorption of paraquat through rabbit skin have been presented by Clark et al. They report that the transfer through the skin is much greater if the applied material is covered with an occlusive dressing. They found that with daily skin applications to rabbits for 20 days, the LD_{50} = 4.5 mg of paraquat ion/kg body weight.

Chronic toxicity experiments have been conducted in both dogs and rats. Feeding of paraquat to dogs at 7.2 and 34 ppm of the diet over a period of 27 months caused no significant abnormalities while some abnormalities were observed at the 85 and 170 ppm levels. Rats fed 170 ppm of paraquat for two years did not reveal significant abnormalities in any of several parameters (Herbicide Handbook WSA, 1967).

The injection of 0.1 ppm of paraquat into fertile eggs resulted in a decrease in hatchability of the eggs. In an effort to find out if this same reduction in egg hatchability could be made to occur by feeding paraquat in the drinking water (Fletcher, 1967) fed paraquat at 40 ppm to hens in their drinking water. No decrease in the numbers of eggs laid or hatchability was observed and Fletcher concluded that normal use of paraquat would present no hazard to poultry or consumer.

Stevens and Walley (1966) have conducted studies on the fate of isotope-labeled paraquat fed to lactating cows. They fed 8 mg/kg of paraquat dichloride in a single dose and then found that less than 0.02% of the radioactivity appears in the milk; this they consider safe for human consumption. Contrary to the report of Daniel and Gage, only 0.26% of the paraquat is excreted in the urine. The bulk of the radioactivity appears in the feces.

The effect of paraquat on fish was studied in a small pond near Denver. Treatment was at 1 ppm and no acute toxic effect was observed on rainbow trout, green sunfish, bluegills and channel catfish but residues were measured in all fish with peak accumulation in 1 to 16 days. No pathology was observed in the 40 specimens examined. Nymphs of the stonefly Pteronarcys were exposed to 1,000 mg/liter of paraquat for 96 hr without effect. Butler (1965) reports that there was no decrease in the growth rate of oyster shell or toxicity to shrimp exposed to 1 ppm of paraquat.

In view of the high toxicity of paraquat to man and the unusual type of irreversible proliferative changes it induces in the lungs, extreme precautions should be employed to protect the user from inhalation of dusts or contact with spray. The potential hazards to wildlife appear to be less than for the man who applies the chemical.

Picloram

One of the newer organic herbicides is 4-amino-3,5,6-trichloropicolinic acid; it usually is called picloram, a name approved by the Weed Society of America, or by its trade name, Tordon.* In discussing the toxicity of this material alone and in mixtures, we shall be particularly concerned with two formulations: (1) essentially pure picloram, and (2) Tordon 101 which is a mixture of triisopropanolamine salts of picloram and 2,4-D as shown below:

* Tordon, registered trademark of Dow Chemical Company.

COMPOSITION OF TORDON 101 MIXTURE
(Military Designation, White)

	Acid Equivalents		Triisopropanolamine Salts
	lb/gal	%	(%)
Picloram	0.54	6.5	10.2
2,4-D	2.0	24.0	39.6

The acute oral toxicities of picloram and Tordon 101 mixture are shown in Table VI-4. It will be noted that picloram would be rated as nontoxic while Tordon 101 would be rated as mildly toxic on the basis of the toxicity designation presented in the USDA Agriculture Handbook 332 (1967).

Experiments on skin irritation and sensitivity have been made on both rabbits and man (Weimer et al., 1967). Prolonged contact of undiluted Tordon 101 mixture with rabbit ears resulted in only slight irritation. Exposure of abraded skin as well as intact rabbit belly skin to a single treatment with Tordon 101 resulted in mild to moderate erythema. Repeated and prolonged contact resulted in eschar formation. The skin returned to normal in 4 to 21 days from onset of exposure. When the experiment was repeated using a 5% solution of Tordon 101 there was no irritation or interference with the healing of the abrasions. Microscopic examination of the various tissues showed no effects attributable to the exposures. The repeated application of a 5% solution of Tordon 101 produced no skin irritation or sensitization (Weimer, 1967).

Sixty-seven rabbits were employed in the eye toxicity tests using various quantities of undiluted Tordon 101. The experiments were made at ambient or high temperatures and humidities. One rabbit receiving 0.05 ml in his eye died but probably from causes other than picloram toxicity. Included in this study were wash-out experiments and use of opthalmic ointments. The symptoms varied from mild to severe blepharitis, severe swelling, mild to severe iritis, and mild to moderate corneal opacity in 39 of the rabbits. Except for the rabbit that died, all rabbits were normal by the 28th day (Weimer, 1967).

A subacute oral toxicity experiment in 22 sheep was conducted for 30 days. Tordon 101 was fed to half the sheep at 0.55 and to half at 0.11 mg/kg; at the higher level one sheep died in five days and another died after 10 days. At the lower dose level there was no adverse effect on weight gain or other sign of toxicity (Weimer, 1967). In another subacute oral toxicity

TABLE VI-4

ACUTE ORAL TOXICITY OF PICLORAM TO ANIMALS

Species	4-Amino-3,5,-6-trichloropicolinic Acid				Tordon 101			
	Dose*	Remarks	LD_{50}	Ref.	Dose	Remarks	LD_{50}	Ref.
Rat (F)			8,200	c/			3,080	a/
Rat				a/				b/
			4.17**	b/				
Mouse (F)			2,000- 4,000	a/				
Guinea Pig (F)			Approx. 3,000	a/				
Rabbit			1.670	1263				
			2,000	a/				
Chicken (M)			6,000	a/				
Sheep	260	No ill effects		a/	1,265	No ill effects	2,000	b/
	390	"		"	1,900	Toxicity but recovered		"
	650	"	> 650	"	2,200	" "		"
	720	"	> 720	"	5,000	" "		"
Cattle	130	"		a/	1,265	No ill effects		b/
	195	"		"	1,900	Toxicity but recovered		"
	325	"		"	2,530	" "		"
	488	"	> 488	"	3,163	" "	> 3,163	"

* mg/kg; ** ml/kg.

a/ Lynn, G. E., A review of toxicological information on tordon herbicides. Down to Earth, 20 (4). 9-11 (1965).

b/ Weimer, J.T., T.A. Ballard et al., Toxicological studies relating to the use of White (Tordon 101) as a defoliant. U. S. Army, Edgewood Arsenal, Pharmacology Labs., September 1967.

c/ U. S. Department of Agriculture, Agriculture Handbook No. 332, Suggested guide for weed control 1967.

test albino male and female rats were fed picloram at dietary levels up to 1,000 ppm which amounted to a daily intake of 75 mg/kg for a total of 90 days. At this dose level and below the picloram was tolerated without evidence of adverse effects as judged by behavior, mortality, food consumption, blood examinations, body and organ weights and gross and microscopic examination of the tissues. At higher levels in the feed, namely 3,000 and 10,000 ppm, moderate changes were observed in the liver and kidneys and a slight decrease in body weight of the females (Lynn, 1965).

A subacute oral toxicity experiment on Japanese quail showed that 100 and 1,000 ppm of picloram in their diet had no ill effects as judged by their appearance, behavior, weight gains, egg production or egg hatchability (Lynn, 1965).

Aerosol toxicity studies were conducted with rabbits exposed to aerosols of Tordon 101 with mass median diameter of 1 μ. The concentration of aerosol which was able to kill 50% of the rabbits (LCt_{50}) was found to be 150,962 mg/min/cu m with the 95% confidence limits falling between 79,358 and 287,252 mg/min/cu m. The animals kept their eyes closed and became inactive during the exposure; four or five days later the survivors showed mild to moderate blepharitis, the eyes were partially closed and the lids were erythematous. The rabbits which died from the inhalation of the aerosol succumbed on the 1st, 5th, 9th and 14th days after exposure (Weimer, 1967).

Chronic toxicity experiments were conducted with rats and beagle dogs with picloram in their daily rations for a period of two years at levels of 15, 50 and 150 mg/kg of body weight per day. At the end of the two years of continuous feeding there was no observable adverse effect on any of the animals of either species as measured by body weight, food consumption, behavior, mortality, hematological and clinical blood chemistry studies and urine analysis. Both males and females of both species were sacrificed at the end of the two years for pathological examination. No gross or histopathological changes could be attributed to the ingestion of picloram. There was also no difference in the incidence or the kind of tumors found between the control animals and those receiving picloram in their diet (Dow Chemical Company, 1965).

In a personal communication from D. D. McCollister of the Bioproducts Department of Dow Chemical Company(McCollister, 1967) , he described the results of fertility, reproduction and teratology studies in rats maintained on diets containing Tordon herbicide (picloram). He summarized these experiments in these words: "The groups of male and female rats were maintained on diets containing as much as 0.3% (3,000 ppm) of TORDON Herbicide through a three-generation, two litter per generation, fertility, reproduction and lactation study without evidence of adverse effect as judged by indices of fertility, gestation, viability, lactation, and by body weight records. Gross and histopathologic examination of tissues from weanlings of the F3b litter was also negative. Teratological studies of fetal skeletal development and of internal anomalies showed no difference between the treated fetuses and the untreated control fetuses."

In order to determine the fate of picloram in the lactating cow Fisher et al. (1965) mixed an acetone solution of picloram with grain so as to leave a residue of 5 ppm on it. This was fed to a cow and the milk and urine collected and analyzed. The analytical method available would not detect less than 2 ppm of picloram and so the milk samples were not analyzed. On the other hand, 97.7% of the picloram administered was recovered unchanged in the urine.

The effect of picloram on soil microorganisms has been reported by Whitworth et al. (1965). Using the method of Professor Clark of New Mexico State University (which employs a king-size Warburg-type of apparatus) they studied the effect of various soil contaminants including picloram on metabolism of a native, mixed microbial culture growing on an extract similar to that found in enriched soil. Picloram at 240 ppm increased the oxygen uptake approximately 20% while at 480 ppm it caused 30% decrease in oxygen uptake. Unpublished information (Goring, 1966) on tests with 45 common soil microorganisms have shown that picloram has little effect on them at concentrations below 1,000 ppm. The growth of one organism, <u>Thiobacillus thiooxidans</u>, was inhibited at 1,000 ppm but not at 100 ppm. At concentrations up to 1,000 ppm there was little effect on total numbers of microorganisms including both bacteria and fungi. Furthermore, at this concentration in the soil, carbon dioxide evolution, nitrification and urea hydrolysis were little affected. Arnold et al (1966) studied the effect of picloram at concentrations up to 50 ppmw on the growth of <u>Aspergillus niger</u> and concluded that it did not inhibit the growth of the fungus at these concentrations, although the herbicide was shown to be present in the fungus mycelium.

The effect of picloram (potassium salt) on the aquatic chain organisms has been reported by Hardy (1966). A study of this kind is particularly important because picloram is not rapidly decomposed in the soil and the residues are likely to find their way into nonflowing waters. He concluded that the potassium salt of picloram at 1 ppm acid equivalent did not affect the growth and reproduction of <u>Daphnia</u> and that there was no buildup of picloram in the tissues. Guppies kept in water with 1 ppm of picloram and fed <u>Daphnia</u> reared in water containing 1 ppm of this herbicide appeared normal in development, behavior and reproduction. Further, 1 ppm of picloram had no adverse effects on algae or on the <u>Daphnia</u> which ate the algae or the fish that ate the daphnia.

Studies of the effect of Tordon 101 on aquatic animals (Weimer, 1967) showed that *Daphnia* can tolerate 380 ppm for 24 hr but that a concentration of 530 ppm kills 95% of them in 24 hr.

The effect of picloram on fish has been reported by Bohmont (1967). He estimated that the lethal concentration (LC_{50}) to rainbow trout is 2.4 mg/liter (2.4 ppm) at 48 hr; similarly the LC_{50} for bluegills is estimated to be 13.1 mg/liter. The Bureau of Commercial Fisheries reports that 1 ppm of picloram has no effect at 48 hr on mullet (*Mugil cephalus*) (1966). They also report no effect for this concentration on eastern oyster (*Crassostrea virginica*) or brown shrimp (*Penaeus aztecus*).

The effect of Tordon 101 mixture to fish has been reported (Weimer, 1967) and the numbers following the names of the fish represent the median tolerance limits in ppm: fathead minnow (64), brook trout (240), brown trout (230), rainbow trout (150); green sunfish (130). The estimated safe limit for continuous exposure for most of these fish is thought to be around 100 ppm.

In summary the acute and long-term data on the toxicity of picloram and Tordon 101 formulations show that when these are used according to label recommendations there is little direct toxicity hazard associated with their use. Obviously some indirect hazards to fish and wildlife may occur as a consequence of their use due to destruction of plants.

The levels of picloram used in Vietnam are well below those at which direct toxicity to humans or wildlife would be expected to occur.

Silvex

Silvex is the common name for 2-(2,4,5-trichlorophenoxy)propionic acid; it has been used extensively for the control of woody plants and on weeds in pastures, crops and aquatic habitats. Much of the following information is taken from a review of some toxicological aspects of silvex (Mullison, 1966). The acute oral LD_{50} is shown for five species: rat, 1,070 mg/kg; guinea pig, 850 mg/kg; rabbit, 850 mg/kg; mouse, 2,140 mg/kg; and chicken, 2,000 mg/kg.

Subacute feeding studies were made with rats which were fed 10, 30, 100, 300 and 600 mg/kg/day of propylene glycol isobutyl ether ester of silvex for a total of 90 days. Some of the rats succumbed at the two highest levels and those which survived lost some weight. Similar studies were made with the sodium and also with the potassium salts of silvex and the results were very similar. Two-year feeding studies were conducted both with rats and dogs and the "no effect" levels were 100 ppm in the diet for rats and 190 ppm in the diet for dogs. In the higher levels there was some liver pathology but no increased incidence of tumors. Palmer et al.(1964) have reported on the toxicological effects of silvex to yearling cattle. Cattle on a daily dosage of 25 mg/kg showed some toxic symptoms but continued to gain weight while one yearling died at the 50 mg/kg dose level after 56 doses. Swelling of the parotid region was one of the toxic symptoms.

The acid of silvex is appreciably irritating to the eyes and skin, particularly in high concentrations. The undiluted esters may cause painful but temporary injury to the eyes. Skin irritation may occur from repeated or extended contact with the skin but there is no evidence of toxicity resulting from skin absorption. There was no sign of allergic response to the application of a 1% solution of a commercial formulation of silvex to the skin of 50 human test subjects.

Studies by the Bureau of Sport Fisheries have shown that the hazard of the butoxyethanol ester of silvex to wildlife is minimal.

	Amount in Food (ppm)	Number of Days	Total Quantity Fed, mg/kg (LD_{50})
Young Bobwhite Quail	5,000	10	9,350
Adult Mallard Ducks	2,500	13	33,700
Young Ring-necked Pheasants	5,000	<100	9,240

Fish, on the other hand, are more susceptible than birds to the butoxyethyl ester of silvex. However, the potassium salt of silvex appears to be less toxic to fish than the ester formulations. No attempt will be made to present all of the fish toxicity data and the reader is referred to the Pesticide-Wildlife studies (1963, 1964), and to the summary by Mullison (1966). Some fish such as the rainbow trout appear at times to be highly resistant to silvex (Cope reports the LD_{50} for a 96-hr exposure to be 1,300 ppm) while at other times they appear to be fairly sensitive to silvex (Fish and Wildlife report a 96-hr LD_{50} of 14.8 ppm). Five out of five fathead minnows were able to survive a 72-hr exposure to 150 ppm of the potassium salt of silvex but other experiments indicate that the safe limit for fathead minnows is between 1 and 3 ppm of the butoxyethanol ester of silvex. Experience with silvex in treated ponds confirms the observation that levels of 3 ppm and above produced liver degeneration lesions, testicular degenerative lesions, atrophy of the spermatic tubules and abnormal spermatozoa on redear sunfish. No comparable changes were seen in the ovaries.

The possible hazard of aquatic weed control procedures to water fowl was considered and analysis of the levels of silvex in the tissues of four ring-necked ducks, six coots, one lesser scaup, one green-winged teal and one gadwall showed low or no detectable residues.

The effect of silvex to possible fish foods has shown that the nymphs of the stonefly (Pteronarcys) could tolerate 5.6 ppm for 24 hr but only 0.32 ppm for 96 hr. Half of the Daphnia magna exposed to 100 ppm of the potassium salt of silvex for 26 hr were immobilized; this is a sign of toxicity but the level is far above the usual 2 ppm used for aquatic weed control.

In summary the toxicity of silvex is not great to animals, birds and other wildlife; however, there is much variability in the response of fish to silvex and some species may be injured or killed at levels normally used for aquatic weed control. The potassium salt appears less hazardous to the fish than the butoxyethyl ester.

Simazine

2-Chloro-4,6-bis(ethylamino)-s-triazine, better known as simazine, is a selective herbicide which has found use in both croplands and noncroplands, but it lacks herbicidal activity until it reaches the plant roots. When used as a pre-emergence herbicide it is applied to soil at the rate of 1 to 4 lb/acre, but when used as a soil sterilant it is applied at the rate of 10 to 40 lb/acre (Klingman, 1961). The mechanism of the phytotoxicity is to block photosynthesis; it has been shown that plants grow well in the presence of toxic amounts of simazine provided they are fed solutions of glucose. Simazine is relatively non-toxic to a variety of animal species as shown by the observation that the LD_{50} for mice, rats, rabbits, chickens and pigeons in all cases exceeded 5,000 mg/kg. Rats survived daily doses of 2,500 mg/kg for four weeks and rats fed for two years on a diet containing 1, 10, and 100 ppm of simazine revealed no symptoms of toxicity (Dalgaard-Mikkelsen and Poulsen, 1962).

Simazine is more toxic to sheep and cattle than atrazine. Sheep were killed by 3 daily doses of simazine at 250 mg/kg, 14 daily doses of 100 mg/kg or 31 daily doses of 50 mg/kg. Cattle were killed by 3 daily doses of 250 mg/kg (Palmer and Radeleff (1964)).

Vivier and Nisbet (1962) in considering the toxicity of commercial formulations of herbicides in relation to water pollution problems conducted studies on the effect of 1.0 ppm of "Herboxy" (0.5 ppm simazine) in a small aquarium without plants. They observed that 60% of the minnows (Phoxinus phoxinus) were killed in three days but later concluded that the anionic detergent in the Herboxy was responsible for this high toxicity.

Johnson (1965) in a study on the control of aquatic vegetation in farm ponds in Ontario used up to 8 lb. of simazine per acre of a mixture (presumably 50:50) of atrazine and simazine at 20 lb/acre and obtained excellent weed control but no apparent damage to any fish.

Additional studies on the use of simazine for the control of aquatic vegetation were reported by Walker (1964). Five formulations of simazine were compared for their relative toxicities to several species of sunfish (Lepomis macrochirus, L. gibbosus, L. microlophus and Micropterus salmoides). These formulations included: 17% simazine on granular ammonium sulfate, 50% wettable powder, 8% on granular attaclay, 4% on granular attaclay and 20% on granular calcium sulfate. The calcium sulfate formulation was much the least toxic and the LD_{50} to sunfish was about 650 ppmw. A series of different fish were studied and it was found that the minnow and catfish families were less susceptible than the sunfish.

Walker (1964) also reported on the effect of simazine on the lake bottom fauna. He found that there were some toxic effect upon the numerical abundance of bottom-dwelling fish food organisms. At high levels of simazine application a layer of simazine precipitation was formed over the bottom mud. This localized the herbicide at the mud-water interface and appeared to pose an obstacle to the bottom-dwelling organisms but the toxic effects were limited.

The hazards to man and to fish and wildlife associated with use of simazine for weed control are not expected to be great so long as the printed label instructions are followed.

Sodium Arsenite

Sodium arsenite is one of the older herbicides and it is generally considered to be more hazardous and less specific in its action than some of the newer herbicides. The fatal dose to man is estimated to be about 0.2 g (Klingman, 1961). It may cause a serious burn to the skin or damage to eyes; therefore, protective clothing and extreme caution are required during its use for weed control. Water containing 0.05 ppm of arsenic is considered unsafe for human consumption. When other herbicides fail to get the job done sodium arsenite is still used in aquatic weed control with little difficulty due to direct toxicity to the fauna.

Meliere (1959) reports that the acute oral mouse toxicity of As_2O_3 (containing 75.4% of metallic arsenic) is 51 mg/kg. The acute oral toxicity of sodium arsenite (100% active) in rats is between 10 to 50 mg/kg (Agricultural Handbook 332, 1967). Edson and coworkers (1963) report that the acute oral toxicity of either sodium or potassium arsenite is 70 mg/kg and that the dermal toxicity on rats is 150 mg/kg. Toxic effects to cattle, deer rabbits, and other wildlife may be encountered if they have access to either the sprayed vegetation or to spilled materials (George, 1960). Apparently the sodium arsenite has a salty taste and is quite attractive to these animals. In one extreme example telephone poles were impregnated with sodium arsenite and cattle were killed by licking the arsenite off of the poles. The poles were removed but then more than a year later deer were killed from eating the sodium arsenite which had washed down the poles to the ground.*

Birds appear to be much more resistant to sodium arsenite than are mammals. In studies by the Fish and Wildlife Service (1963) 26 adult mallard ducks were fed a diet containing 100 ppm of sodium arsenite for 128 days; during this period each bird received 8 mg/day or a total dose of 973 mg/kg and there were no deaths.

A number of studies have been made on the tolerance of fish to sodium arsenite. Clemens and Sneed (1959) have found the LD_{50} of sodium arsenite for channel catfish exposed for 96 hr to be 25.9 ppm. Johnson (1965) reports that 3 to 8 ppm of sodium arsenite is required to control filamentous algae and submerged aquatics in ponds. These concentrations have no effect on the numbers or survival of pond invertebrates including midge larvae (Chironomidae) beetle larvae and adults (Haliplidae), true bugs (Notonectidae, Gerridae, Nepidae and Belostomidae), may fly larvae (Baetidae), damselfly larvae (Coenagrionidae), dragonfly larvae (Libellulidae) and amphipods (Amphipoda). At 5 ppm there was no effect on the rainbow or brook trout.

Crosby and Tucker (1966) have found the concentration of sodium arsenite needed to immobilize 50% of Daphnia magna to be 6.5 ppm. In their opinion this is a better index of toxicity for this organism than the dose lethal to 50%. They are concerned about the possible serious damage to the elementary link in the food chain which may occur when sodium arsenite is used at 10 ppm for the control of aquatic weeds. They added that there need be little concern about direct toxicity of sodium arsenite to rainbow trout (LD_{50} = 60 mg/kg) or to the bluegill (LD_{50} = 44 mg/kg).

Cope (1966) reported the effect of repeated applications of sodium arsenite to several ponds on the weight gain, pathology and residues of the bluegills in those ponds. Sixteen weekly treatments at the highest level, 0.69 ppm, resulted in 11.60 ppm in adults and 11.70 ppm in the immatures. Throughout the study the adult and immature bluegills stored arsenic at essentially the same rates. At the end of the experiment this pond contained 9.04 ppm and

* Personal communication from Dr. James Jenkins, Professor of Zoology, University of Georgia, October 18, 1967.

the mud 109.9 ppm. Analyses of tissues and organs of fish whose whole body arsenic content was 2.61 at 16 weeks (from a different pond) showed the following amounts in ppm: muscle 1.36, skin and scales, 2.41; gills and digestive tract, 17.60; liver, 11.60; kidney, 5.89 and ovaries 8.39. These data indicate that arsenic does accumulate in bluegills.

Bluegills exposed to 4 mg/liter (4 ppm) of sodium arsenite showed no pathology for the first few weeks. After that, kidney and liver damage appeared and ovaries exhibited degenerative lesions. An interesting point revealed by these pathological studies is that nematodes in the pyloric caecae in the beginning of the experiment disappeared after two weeks (Cope, 1966). It was also observed that the presence of sodium arsenite inhibited the growth rate of these fish during the 16-week exposure.

Walker (1962) has studied the effect of 2.5 to 20 ppm of sodium arsenite on aquatic organisms which might be important in the diet of certain fish. He concludes that both the numbers and weights of these organisms decrease.

We have not given a complete review of the literature on this herbicide since we already know that it is hazardous and that its use should be avoided whenever possible. The data presented here indicate, however, that cacodylic acid is less toxic than sodium arsenite.

Sodium Chlorate

Sodium chlorate is an inexpensive, long lasting soil sterilant in dry areas and relatively temporary in humid ones. Large quantities have been used for more than 40 years for railroad rights-of-way maintenance, killing of farmyard vegetation, and other areas where nonselective kill of vegetation is required. The chemical may be applied at the rate of 1 to 2 lb/100 sq. ft. or about 870 lb/acre. The Herbicide Manual (Dunham, 1965) recommends about 480 lb/acre. Caution must be exercised with the use of this material since dry organic matter impregnated with it is very highly flammable. For this reason mixtures of sodium chlorate with other inorganics such as soluble borates or calcium chloride are used to decrease the flammability hazard.

The acute oral toxicity of sodium chlorate has been placed at between 1,200 mg/kg (Dalgaard-Mikkelsen and Poulsen, 1962) and 5,000 mg/kg (Herbicide Handbook WSA, 1967). In spite of its relatively low toxicity there have been a number of human deaths resulting from its use in oral hygiene. There have been some reports of poisoning of domestic animals, too, following oral ingestion. Another problem is due to its salty taste and the fact that it can make poisonous plants more palatable to cattle. The mechanism of mammalian toxicity involves the formation of methemoglobin and its usual consequences. Rudd and Genelly (1956) report that aquatic animals are destroyed by 20,000 to 40,000 ppm, the levels required to kill submerged aquatic plants. The toxic threshold for flat worms is 12,500 ppm and for Daphnia is 4,240 ppm. Fish are quite susceptible to sodium chlorate.

TCA

Trichloroacetic acid (TCA) is usually formulated as the sodium salt (82.8% acid equivalent) and is used to control grasses such as bermuda grass, cut grass, tall larkspur, panicum, paragrass or cattails. When tillage is possible the accepted treatment rate is 30 to 40 lb/acre; if not, the quantity may be increased to 125 to 150 lb/acre (Dunham, 1965). Acute oral toxicities (LD_{50}): mice, 3,640 mg/kg; rats, 5,000 mg/kg; rabbits, 4,000 gm/kg; chicks, 4,280 mg/kg (Herbicide Handbook WSA, 1967).

The solid or strong aqueous formulations of TCA sodium salt are likely to cause painful burns if permitted to remain on the skin for an hour or more (Duham, 1965). TCA in the eyes can be exceedingly painful and serious injury can develop. The dust or aerosols can be very irritating to the nose but these are not likely to produce systemic injury.

In a 126-day feeding study with 0.1% TCA in the diet there was no adverse effect; with 0.3% TCA in the diet there was a reduction in growth rate which probably reflected the fact that the animals do not like the taste of TCA.

Cattle, horses, sheep and swine suffered no ill effects when pastured for two weeks on a field treated with sodium TCA at the rate of 140 lb/acre. These animals also had access to unsprayed areas and chose not to eat the sprayed forage (Grigsby and Farwell, 1950).

TCA and its sodium salt have a low order of toxicity to fish and wildlife. Channel catfish survived a 96-hr exposure to 2,000 ppm of TCA (Lawrence, 1964). Chinook salmon survived 48-hr exposure to 870 ppm of TCA (Bond, 1959).

In spite of the high levels of this material which are used (up to 150 lb/acre) little hazard (other than possible skin burns during careless handling of the concentrate) to man, livestock or to aquatic animals is expected to result.

2,3,6-TBA

2,3,6-Trichlorobenzoic acid is primarily used for the control of broadleaf, deep-rooted, noxious perennial weeds such as field bindweed, leafy spurge, Canada thistle, Russian knapweed, bur ragweed, blueweed climbing milkweed, honeysuckle, trumpet vine, balsam, fir, cedar and many others. The usual application rates vary and are 10 to 20 lb/acre for noxious perennials, 20 to 30 lb/acre for control of mixed broadleaf plants for more than one year, 10 to 20 lb/acre for control of woody vines and 4 lb/acre for woody brush. The acute oral toxicities in rats are 750 to 1,000 mg/kg for the acid and 1,644 mg/kg for the dimethylamine salt. Several oral doses of 750 mg/kg of the sodium salt of 2,3,6-TBA to rats produced no unusual changes. Skin irritation tests on shaved guinea pigs showed that an aqueous solution, 2 lb. ae/gal, was moderately irritating while a solution containing 0.8 lb. ae/gal was mildly irritating. Skin irritation and edema occurred on the application of 2,3,6-TBA to rabbits. Cutaneous skin absorption tests with a 25% solution showed that no deaths were caused to any animals (Herbicide Handbook WSA, 1967). Davis and Hardcastle (1959) have reported on the median tolerated limit (TL_m) of 2,3,6-TBA for sunfish and bass at 24 and 48 hr:

	24 hr	48 hr
Sunfish	1,800 ppm	1,750 ppm
Bass	1,500 ppm	1,250 ppm

There are not much data on the effect of this material on wildlife but we conclude that it is much less toxic to animals than some of the other herbicides which would be applied at the same quantitites per acre.

2,4-D

2,4-Dichlorophenoxyacetic acid or 2,4-D, its esters, salts and amides, have found wide acceptance for the control of broadleaf plants. Many of the investigators who have considered the toxicity of 2,4-D have oversimplified the situation by assuming 2,4-D acid and its derivatives and formulations all have the same toxicity based upon the acid equivalent. This generalization is a useful one in view of the magnitude of the literature; however, there are some notable exceptions and a few of these will be pointed out later in this section.

There has been some alarm (perhaps unjustified) about the human toxicity resulting from the use of 2,4-D and its derivatives. Some of the case histories of persons contracting neuropathy as a result of 2,4-D treatment are presented here to permit the reader to form his own opinion about the magnitude of the hazard associated with the use of 2,4-D compounds. Goldstein et al. (1959) in their report on peripheral neuropathy after skin exposure to an ester of 2,4-D state that three individual patients, two farmers and a female bookkeeper, suffered the disorder some hours after exposure to the 2,4-D formulation while attempting to kill weeds. The symptoms progressed through a period of days until pain, paresthesias and paralysis were severe. Disability was protracted and recovery was incomplete even after a lapse of years. They concluded that there was little doubt that the symptoms resulted from the percutaneous absorption of the 2,4-D. The electromyographic examinations supported the diagnosis of peripheral neuropathy. Berkley and Magee (1963) report a similar case of neuropathy in a 39 year old farmer four days after exposure to 2,4-D dimethylamine salt; the symptoms included numbness and incoordination of the hand and finger muscles and a slow recovery. These authors conclude that persons who get peripheral neuropathy from exposure to 2,4-D are very rare compared to the number of exposures there must be. They state that some individuals may have a predisposition to neuropathy and suggest that all users of these herbicides use protective clothing and wash immediately with soap and water in case of accidental exposure.

Mitchell (1946) quotes the experimental work of E. J. Kraus concerning the ingestion of 500 mg of purified 2,4-D/day by a man over a period of 21 days without ill effect. Seabury (1963) reports on the administration of the sodium salt of 2,4-D to two patients suffering from coccidioidomycosis. The first patient received an intramuscular injection of 2.0 g without any toxic reactions. The second patient received 3.6 g by parenteral injection; there were severe toxic reactions including coma, fibrillary twitching of some muscles, hyporeflexia and urinary incontinence. Recovery from the toxic effects of the injections were complete in 48 hr but the patient died of his disease 17 days after the injection.

According to DiPalma (1965), a man committed suicide by consuming about 6.5 g of 2,4-D; from this and the other information, it appears that the lethal dose for a human lies in the range of 50 to 100 mg/kg.

The acute oral toxicity of 2,4-D in rats and various other animals is shown in Table VI-5. It will be noted, however, that dogs appear to be most sensitive ($LD50 = 100$ mg/kg) and that birds are the least sensitive (LD_{50} = 2,000 to 4,000 ppm). A comparison of the LD_{50} for rats of the different 2,4-D compounds shows that for the rat, at least, the acid may be a little more toxic than the sodium salt or the esters but the difference is small. In chicks, however, the 2,4-D acid (LD_{50} = 541 mg/kg) is more than three times more toxic than the mixed butyl esters of 2,4-D (2,000 mg/kg).

Dr. O. G. Fitzhugh (1967), Toxicological Advisor, Division of Toxicological Evaluation, Food and Drug Administration, writes that the FDA

TABLE VI-5

ACUTE ORAL TOXICITY OF 2,4-D

Species	Sex	LD_{50} (mg/kg)	Remarks	References
Rats		666	Acid	Hill (1947)
Rats		1,500	Butyl "ether" (ester)	Schillinger (1960)
Rats		2,000	Sodium Salt	" "
Rats	M	375	Acid	Rowe et al. (1954)
Rats	F	805	Sodium Salt	" " "
Mice	M	375	Acid	Hill (1947)
Mice	M	367	Acid	Rowe et al. (1954)
Guinea Pig	M+F	469	Acid	" " "
Guinea Pig	M	551	Sodium Salt	" " "
Rabbit		800	Acid	Hill (1947)
Monkey		214	Acid, Survived	" "
Dog		100	Form not Stated	Stupnikov(1966)
Cattle		500-2,000	" " "	" "
Birds		2,000-4,000	" " "	" "
Chicks		360-820	" " "	" "
Honey Bee		104.5 (μg)	" " "	" "
Chicks	M+F	541	Acid	Rowe et al. (1954)
Dog		100	Acid	" " "
Chicks		380-765	Alkanolamine Salt	" " "
Mice		375	Sodium Salt	" " "
Rabbit		800	Sodium Salt	" " "
Rats	M+F	700	Isopropyl Ester	" " "
Guinea Pigs	M	550	Isopropyl Ester	" " "
Mice	M	541	Isopropyl Ester	" " "
Chicks	M+F	1,420	Isopropyl Ester	" " "
Rats	F	620	Mixed Butyl Esters	" " "
Guinea Pigs	F	848	Mixed Butyl Esters	" " "
Rabbit	F	424	Mixed Butyl Esters	" " "
Mice	F	713	Mixed Butyl Esters	" " "
Chicks	M+F	2,000	Mixed Butyl Esters	" " "
Rats	F	570	Mono-,di-, tripropylene-glycol Butyl Ether Esters	" " "

laboratories have conducted two-year feeding studies in both rats and dogs and they have conducted a three generation, six litter reproduction test in rats:

1. In the two-year feeding test on dogs there were three male and three female dogs in each group. The levels of 2,4-D in the diets were 0, 10, 50, and 500 ppm 2,4-D. There were no gross or microscopic findings related to 2,4-D. There was no dose-related clinical or hematologic effect. The "no effect" level was greater than 500 ppm (i.e., not determined).

2. In the two-year rat feeding study there were 25 male and 25 female rats per group. The diets of the various groups contained 0, 5, 25, 125, 625, or 1,250 ppm of 2,4-D. There was no effect on growth, survival, organ weights, hematologic values or occurrence of tumors. Neither gross nor microscopic changes were noted. No "no effect" level was found (i.e., greater than 1,250 ppm).

3. In the rat reproduction studies 20 males and 20 females were used (i.e., where there were enough survivors) and they were fed 0, 100, 500 or 1,500 ppm of 2,4-D in their diets. No effect was observed at the 100 or 500 ppm levels. At the 1,500 ppm level, there was no effect on fertility nor on the average number of pups/litter. There were, however, significant effects on the average number (%) weaned and also on the weights of the weanlings (i.e., average weight of survivors). No histopathology was done and the "no effect" level is at least 500 ppm but less than 1,500 ppm of 2,4-D in the diet.

Palmer (1963) conducted a chronic toxicity test with yearling steers using an alkanolamine salt of 2,4-D (2,4-D Dow Weed Killer Formula 40). He found that 112 daily doses of 50 mg/kg of this 2,4-D salt had no deleterious effect on the steer and concluded that it was not accumulated in the steer since doses of 100 and 250 mg/kg had produced toxic symptoms. Clark (1964) confirmed this observation by a study on the fate of 2,4-D in sheep using C^{14} labeled 2,4-D. He showed that 96% of the 2,4-D was excreted unchanged in the urine in 72 hr. About 1.4% of the radioactivity was found in the feces during this same period. A similar study was reported by Khanna and Fang (1966) in which they fed C^{14} labeled 2,4-D to rats; they found that the time required for elimination was dependent upon the dose. For example, a 1 to 20 mg/rat dose was 88.8 to 95.6% eliminated in 24 hr. At a dose of 100 mg/rat, 144 hr was required for 75.5% recovery of the radioactivity.

Grigsby and Farwell (1950) sprayed alfalfa and brome grass with two to four times the usual quantities of 2,4-D (sodium salt, alkanolamine salt and isopropyl esters used in separate experiments) and then fed it to sheep, chickens, swine, dairy cows and steers. They concluded that these 2,4-D compounds were not injurious to livestock under these conditions. They did, however, note an off-flavor in the milk. Buck et al. (1961) fed herbicide-treated plants in an effort to determine whether the spraying of toxic weeds would make them more palatable to cattle and it did not. There is, however, an authenticated case in which sugar beet leaves accidently sprayed with 2,4-D accumulated enough nitrate to become toxic (Stahler and Whitehead, 1950). This does not seem to be a severe practical problem since sugar beets are very sensitive to 2,4-D, and are not normally sprayed. Some early reports on the increase in HCN content in wild cherry after spraying have now been disproved; instead the level of HCN decreases steadily for 15 days (Lynn and Barrons, 1952) after application of the 2,4-D.

Beekeepers have suffered large economic losses due to the extreme toxicity of the chlorinated insecticides. The effect of herbicides is much less and may at times even be beneficial. Palmer-Jones (1964) applied 2,4-D dust directly to honey bees and also placed it in the hive entrance so the bees would crawl in it. Neither the adult honey bees nor the brood were adversely affected. Beilmann (1950) suggests that the control of brush with 2,4-D may actually improve the bee pasture. He cites an instance where there was much more clover after killing of the brush. Johansen (1965) says that 2,4-D and related compounds are not toxic to bees; however, certain formulations containing isopropyl esters or alkanolamine salts are toxic.

As may be seen from Table VI-6, it does make a difference which compound is used in aquatic weed control. It is readily apparent that the amine salts are less toxic to these fish than the esters. The effect of 2,4-D on fish-food organisms is shown in Table VI-7. It appears that 1 ppmw of 2,4-D gives about 43% reduction in weight of fish food in one week and about 90% in one year; it should be borne in mind that these data were collected in plastic enclosures and the data may not be strictly comparable to the results expected in field use of this herbicide. Table VI-2 presents some data on the effect of herbicides on estuarine organisms including specifically oysters, shrimp, juvenile fish and phytoplankton. This table shows the activities of some other herbicides of interest to this particular report. Rawls (1965) also studied the effect of the 2,4-D herbicides on caged blue crabs (*Callinectes sapidus*), eastern oysters (*Crassostrea virginica*), soft shell clams (*Mya arenaria*), and various species of fish. Under conditions used to control Eurasian milfoil (*Myriophyllum spicatum*) only 2,4-D acetamide at 20 lb/acre (ae) was toxic to the test animals; the butyl and isooctyl esters were effective and nontoxic.

We conclude that the risk of human and animal toxicity from the use of 2,4-D and its various esters and salts is very, very low. Its possible effects on fish and/or fish foods may be a problem under certain conditions; care should be taken to select a 2,4-D formulation, application level and procedure which will minimize these unnecessary disturbances of fresh-water ecosystems.

TABLE VI-6

EFFECT OF VARIOUS 2,4-D COMPOUNDS ON FISH
(after J. M. Lawrence, 1966)

Compound of 2,4-D	Conc. (ppm)	Species	Time (hr)	Remarks
Alkanolamine salt	435-840	Bluegill	48	LD_{50}
Dimethylamine salt	166-458	Bluegill	48	LD_{50}
Isooctyl ester	8.8-59.7	Bluegill	48	LD_{50}
Dimethylamine salt	10	Fathead Minnow	96	LD_{50}
Acetamide	5	Fathead Minnow	96	LD_{50}
Oil soluble amine salt	2	Bluegill, Fathead Minnow	4 (mo)	LD_{10}
Propylene glycol butyl ether ester	2	Bluegill, Fathead Minnow	4 (mo)	LD_{10}
Butoxyethyl ester	2	Bluegill, and Fathead	72	LD_{70-100}
Butyl and isopropyl esters, mixed	1.5-1.7	Bluegill	48	LD_{50}
N,N'-Dimethyl coco-amine salt	1.5	Bluegill	48	LD_{50}
Ethyl ester	1.4	Bluegill	48	LD_{50}
Butyl ester	1.3	Bluegill	48	LD_{50}
Isopropyl ester	1.1	Bluegill	48	LD_{50}
Duomeen-O-amine salt	0.5	Fathead Minnow, Bluegill	4 (mo)	--

TABLE VI-7

AVERAGE NUMBERS OF BOTTOM ORGANISMS PER SQUARE FOOT FOLLOWING APPLICATION OF 2,4-D RANGING FROM 1 TO 4 PPMW IN SIX PLASTIC ENCLOSURES, 1958-1959

Taxonomic Group	Control	One Week	Six Weeks	12 Months
Mayfly nymphs	4.00	0.17	0.17	--
Horsefly larvae	12.44	4.50	4.50	3.67
Common midges	17.11	4.50	1.50	0.33
Mosquitoes	0.44	0.33	--	--
Phantom midges	3.00	1.00	3.33	0.33
Biting midges	1.22	0.33	0.50	--
Caddis fly larvae	2.78	1.33	0.17	0.33
Damselfly nymphs	0.22	0.17	--	0.67
Water beetles	0.02	--	0.17	3.33
Aquatic worms	24.11	10.00	4.50	1.67
Leeches	0.11	--	--	--
Clams	5.44	--	--	--
Snails	5.67	0.50	--	--
Total numbers	76.56	22.83	14.83	10.33
Total weight	1.299	0.733	0.175	0.127

Source: C. A. Walker, Toxicological effects of herbicides on the fish environment. Missouri University Engineering Extension series 2. Proceedings of the 8th Annual Air and Water Pollution Conference 1962, pp.17-34.

2,4,5-T

2,4,5-Trichlorophenoxyacetic acid or simply 2,4,5-T is an important chlorophenoxy-herbicide that is widely used as its ester in combination with an ester of 2,4-D. 2,4,5-T is also used some as its sodium salt or as its triethanolamine salt. It is used for the control of those broadleaf plants for which it is selective in pasture improvement and also in the control of some aquatic weeds; however, it does not kill grasses and some woody species are not controlled.

The acute oral toxicities of 2,4,5-T and three of its esters are given in Table VI-8. 2,4,5-T is generally considered to be slightly more toxic to animals than 2,4-D but the differences are small for most animals.

Drill and Hiratzka (1953) conducted a 90-day feeding test on dogs using 2,4,5-T. The dosages given 5 days a week were 2, 5, 10 and 20 mg/kg. The dogs fed at the 20 mg/kg dose level died between the 11th and 59th days while the other dogs survived for the entire test period. Those dogs on the 10 mg/kg level lost a little weight but all survived; none of the surviving dogs showed any change in organ weights or blood count.

Grisby and Farwell (1950) studied the effect of 2,4,5-T isopropyl ester on the palatability and toxicity of sprayed forage (4 lb/acre) to horses, dairy and beef cattle, sheep, swine and chickens. They observed no toxicity from the consumption of the sprayed forage and neither a preference nor a non-preference for it.

In view of the large use of 2,4,5-T esters in combination with 2,4-D esters much of the toxicity testing has been done on mixtures of these. Dow Chemical Company's product, Esteron* brush killer, and the military herbicide called Orange are both mixtures of 2,4-D and 2,4,5-T esters. More precisely, Orange consists of a 50:50 mixture of the n-butyl esters of 2,4-D and 2,4,5-T. The military herbicide, Purple, for which we have toxicity data is nearly identical with Orange, but it consists of 50% butyl ester of 2,4-D, 20% isobutyl ester of 2,4,5-T and 30% n-butyl ester of 2,4,5-T. Table VI-9 summarizes the acute toxicity of Purple when administered to rats, rabbits and dogs by various routes.

Rowe and Hymas (1954) fed 1,000 mg/kg of Esteron brush killer to a 291 kg steer and detected no sign of toxicity. When this treatment was repeated for a total of three doses on each of three consecutive days, the steer died. At 250 mg/kg/day a steer was able to tolerate 15 doses without outward signs of toxicity; the animal was sacrificed and very minor pathology was noted.

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* Registered trademark.

TABLE VI-8

ACUTE ORAL TOXICITY OF 2,4,5-T

Species	Sex	LD_{50} (mg/kg)	Compound of 2,4,5-T
Rats	M	500	Acid
Mice	M	389	"
Guinea pigs	M&F	381	"
Chicks	M&F	310	"
Dogs	-	100	"
Rats	M&F	495	Isopropyl ester
Guinea pigs	F	449	"
Mice	F	551	"
Rat	F	481	Mixed butyl esters
Rabbit	M	712	"
Mice	F	940	"
Guinea pigs	F	750	"
Rats	F	750	Mixed amyl esters

Source: V.K. Rowe and T.A. Hymas, Am. J. Vet. Res., 15 (57), 622-629 (1954).

TABLE VI-9

ACUTE TOXICITY OF PURPLE

Route	Toxicity	Dosages, mg/kg Rat	Rabbit	Dog
Oral	LD_{50}	566	-	-
	LD_1	213	-	-
Intraperitoneal	LD_{50}	586	1,994	a 500
	LD_1	121	363	> 250
Intrathecal	LD_{50}	569	-	a 500
	LD_1	244	-	> 250
Percutaneous	LD_{50}	5,562	12,034	-
	LD_1	3,178	493	> 1,250

LD_{50} = the dose lethal to 50% of the animals
LD_1 = the dose lethal to 1% of the animals

Source: Dr. B.P. McNamara, Pharmacology Laboratories, U.S. Army Edgewood Arsenal.

Studies on the toxicity of 2,4,5-T to fish have been reported by a number of investigators. Hughes and Davis (1963) have compared the 48-hr median tolerance limit (TL_m) of bluegill sunfish to one salt and five ester products of 2,4,5-T:

Compound of 2,4,5-T	48-hr TL_m (ppm, ae)
Dimethylamine salt	144.0
Isooctyl ester, supplier A	31.0
Isooctyl ester, supplier A	26.0
Isooctyl ester, supplier B	10.4
Propylene glycol butyl ether ester	17.0
Butoxyethanol ester	1.4

They concluded that 2,4,5-T compounds were in general more toxic than the corresponding 2,4-D products but they were unable to explain the differences observed in the toxicities of the isooctyl esters of 2,4,5-T from different suppliers. Butler (1965) has reported the effects to 2,4,5-T acid and polyglycolbutyl ether ester on oysters, shrimp and juvenile fish and the data are presented in Table VI-2.

In summary, 2,4,5-T resembles 2,4-D in its toxicity to animals and fish but is a little more toxic. Since these two compounds are used together, we have reported toxicity data on the mixture. No synergistic toxicities were noted in animals as a result of using these mixtures.

C. Effects of Herbicides on Microorganisms

Microorganisms in the soil, particularly the bacteria, fungi and the actinomyces, play a vital role in the destruction of excess plant and animal waste materials and convert them into carbon dioxide, water and plant nutrients. The three main types of bacterial processes occurring and which improve the fertility of the soil are (1) ammonification or the conversion of proteins and other complex nitrogenous materials to ammonia by organisms such as *Bacillus cereus* or *Pseudomonas fluorescens*, (2) nitrification or the process of converting ammonia to nitrate ions by organisms such as *Nitromonas* and *Nitrobacter sp.*, and (3) nitrogen fixation or the conversion of atmospheric nitrogen into a form usable by plants. The two important kinds of nitrogen fixation by microorganisms are illustrated first by the *Azotobacter sp.* which fix nitrogen directly in the soil and, secondly, by the nodulating bacteria such as the *Rhizobium sp.* In the latter case these organisms also live in the soil but they infect the roots of the legumes to form the root nodules where the nitrogen is fixed. There are other important types of microbial activity carried on in the soil; one of these is the detoxification of chemical pesticides in the soil. However, the effect of microorganisms on herbicides will be discussed later in this report (see Chapter VIII).

It is clear then that knowledge of the effect of herbicides have on microorganisms could be important to the production of crops or the maintenance of wildlife habitat. The following specific examples will serve to illustrate the kinds of observations which have been reported, although the reader is referred to the summary reports of Audus (1964), Yamaguchi (1959), and of Fletcher (1960) for more detailed information.

Pearce (1958) reports that perfusion of soil with 2,4-D solutions increases the overall metabolic rate of the soil microorganisms; Fletcher (1960) reports that at the concentrations usually employed in the control of weeds, the total number of microorganisms in the soils is not greatly affected. One should not conclude, however, that 2,4-D and 2,4,5-T have no effect on the organisms since Worth and McCabe (1948) have found that 1 and 2% 2,4-D solutions will inhibit the aerobic organisms but will have little effect on the facultative anaerobes. This observation was confirmed by Newman and Downing (1958) who found gram-positive bacteria were more sensitive to 2,4-D and 2,4,5-T than were the gram-negative bacteria. Stapp and Freter (1952) found that spore-forming bacteria were more susceptible to 2,4-D than were the nonspore formers. The actinomycetes seem to be relatively insensitive to the phenoxy herbicides but in one test by Baldacci and Amici (1954) and Baldacci (1955), eight out of 40 strains were inhibited by 400 ppm of 2,4-D. Stephenson and Mitchell (1945) report that on the whole the fungi are more resistant to the phenoxy herbicides than are the bacteria.

There are some reports that the phenoxy herbicides stimulate an increase in the number of organisms in the soil. Westlake (1955) found that barley plants sprayed with 2,4-D showed a temporary increase in the number of bacteria in the thin film of soil surrounding the roots. This was explained as due to a change in the permeability of the membranes of the root cells and the outflowing of nutrients for the bacteria.

The effect of 2,4-D on the proteolytic and deaminating activity of selected soil bacteria has been investigated by Johnson and Colmer (1955a,b); they found that concentrations normally applied in the field had little effect on the activities of Bacillus cereus or Pseudomonas fluorescens. The nature of the substrate used for growing these organisms affected the degree of inhibition obtained with higher levels of herbicide. Flieg (1952) was not able to detect any inhibitory effect of 10,000 ppm of 2,4-D on the ammonification process. Simazine and other triazine herbicides were similarly without effect on the ammonification process according to Pochon et al. (1960).

Apparently the phenoxy herbicides have little or only a very temporary effect on the nitrification of ammonia. Flieg (1952) reports that normal concentrations of 2,4-D do inhibit the nitrification reaction in the laboratory; however, the addition of soil to his system permitted nitrification to proceed normally. Slepecky and Beck (1950) also found that 50 ppm of 2,4-D gave inhibition of the nitrification reaction but that inhibition disappeared rapidly during percolation. Similar results were obtained by Pearce (1958) using 100 ppm of 2,4-D and percolating it through garden loam. This release of inhibition may have been due either to adsorption of the herbicide or its microbial destruction.

W. R. Arnold et al. (1966) reports that Aspergillus niger v.T. ATC 6275 proliferation was reduced by 2,4-D at 10 and 50 ppm while picloram at soil application rates up to 50 ppm did not reduce the growth of this fungus. A. niger degraded both 2,4-D and picloram, but 2,4-D was more effective. Both herbicides were found in the fungus mycelia. Organisms using this fungus as a food source would be expected to receive high doses of these herbicides. H. C. Bounds and A. R. Colmer (1965) report that 2,4-D, Silvex, 2,4,5-T, and fenac are degraded and detoxified by Streptomyces viridochromogenes; this is another example of a specific organism which is not inhibited by these herbicides. C. Goring and co-workers (1967) have studied the effects of 1,000 ppm of Tordon on the soil microorganisms and have concluded that it does not seem to have a significant gross effect on either fungi or bacterial populations of soil.

Anderson and Baker (1950) have done quantitative studies on the effects of 2,4-D on pure cultures of various microorganisms. They report that there is some inhibition of the organisms but after the addition of colloidal soil to tie up the herbicide, the microorganisms grow normally. The efficiency of nodulation of leguminous plants is reduced by 2,4-D and beans grown in soil treated with 2,4-D (both the first and second crops after 2,4-D treatment) had lowered protein contents but the reason is unknown. Payne and Fults (1947) have also shown that 2,4-D appears to slow down the nodulation on soybean plants but this does not appear to present any practical problems since the bean plants themselves are exceedingly sensitive to the phenoxy herbicides, and it is unlikely that one would attempt to grow beans on fields freshly sprayed with these herbicides.

In summary, there is good evidence that application of herbicides to plants at the usual levels produces at most a slight reduction of the total numbers of bacteria and fungi in the soil and these return to normal levels within a short period of time in warm moist soil.

D. Toxic Effects of Herbicides and Conclusions

As mentioned in the introduction of this chapter, we are listing here a variety of information which could not properly be listed in the other sections. The items specifically included here are the following: (1) the mutagenic activity of herbicides on plants, bacteriophage, and bacteria, (2) the effect of herbicides on the embryonic development of beetle, (3) the concentration of herbicides in the tissues of fish, (4) the importance of selecting a formulation which will minimize the hazards of herbicides in aquatic environments, (5) an estimation of the hazard involved in the spraying of a man with herbicides,and (6) some general conclusions about the toxicity hazards relative to the use of herbicides.

Mutagenic Effects

Some of the persons who are critical of the use of herbicides feel that we are creating a monster which will eventually destroy us. One area of expressed concern deals with the possibility that herbicides will produce heritable changes in the genetic material of plants. The resulting plants, they fear, will no longer meet our need for the production of foods or they may be insidious weeds which do not respond to either chemical or biological control measures. Some studies have been conducted to determine the likelihood that herbicides may produce heritable changes in plants.

Doxey and Rhodes (1949) conducted a study of a plant-growth-regulator type of herbicide known as 4-chloro-2-methylphenoxyacetic acid (MCPA). In this study they exposed onion root tips to MCPA and observed the effects of this treatment on cell division and on the chromosomes. Chromosome "stickiness" and breakage were observed and the effects were judged to be similar in many respects to changes in mitosis produced by X-irradiation. In a series of three papers, Unrau and Larter (1952) and Unrau (1953 and 1954) discuss their findings on the effect of 2,4-D on the genetics of wheat and barley. The seed grain fields were sprayed with 8 to 16 oz of 2,4-D (EE) per acre 30 days prior to cytological examination. The chromosomes were studied in detail in those cells that were dividing during the process of pollen formation. Regardless of the date of application or the concentration of treatment, the herbicide caused "highly significant" abnormalities of chromosome behavior and the changes were visible as much as 30 days after treatment. Unrau warns that indiscriminate use of herbicides could have grave and far-reaching consequences especially in relation to the prime seed stocks of seed growers. There is reason to suspect that the herbicide interferes with self-pollination and this could explain the increase in the number of off-types or crosses obtained in Unrau's experiments.

Muhling et al. (1960) has studied the cytological effects of 2,4-dichlorophenol, 2,4-dichlorophenoxyethanol, 2,4-D, and other herbicides on pea seedlings (Pisum sativum). 2,4-D was clearly shown to be a prophase poison and to produce spindle inhibition resulting in chromosome configurations very similar to those produced by colchicine.

Dr. Kenneth J. Andersen (1967), Senior Research Microbiologist at Battelle Memorial Institute, Columbus Laboratories, is engaged in a research program for the United States Department of Agriculture to determine the possible mutagenic and genetic effects of the herbicides. As a part of this study, he grew histidine-requiring mutants of Salmonella typhimurium on a histidine-deficient medium to screen 120 of the 130 herbicides listed in the journal, Weeds. These included, 2,4-D, 2,4,5-T, picloram and cacodylic acid and the other herbicides which are currently important for noncropland vegetation control (see Table II-2). Since the S. typhimurium used is histidine-dependent it does not grow very well on the deficient medium unless there is a mutation which eliminates the histidine requirement. In his experiments he found that diethyl sulfate, beta-propiolactone, acridine mustard (ICR-91) and N-methyl-N'-nitro-N-nitrosoguanidine all produced the mutations required for the growth of the organism. On the other hand, none of the herbicides caused this mutation.

A second approach to the problem involved the use of T_4 bacteriophage to detect chemically induced mutations of the rII type. The number of mutant plaques, which characteristically were larger, with a clear center and a sharp edge, were compared to the normal T_4 plaques which were small, with a clear center surrounded by a halo. In addition to this characteristic plaque morphology, rII mutants form plaques on Escherichia coli but not E. coli KB while wild type T_4 bacteriophage forms plaques on both of the E. coli strains. In this evaluation system noninhibiting levels of the compounds (approximately 20 µg-1 mg/20 ml) were employed. The rate of spontaneous mutation (no test chemical present) by T_4 bacteriophage to the rII-type mutant, was about 0.11%. In the presence of the known mutagen, 5-bromouracil, the mutation frequency increased to about 2.5%. In the test system it was concluded that none of the herbicides were mutagenic.

Dr. Andersen has also performed experiments using a 2-aminopurine-induced rII mutant of T_4 bacteriophage to detect revisions from the mutant to the wild type which might be caused by the herbicides. Herbicides, in this detection, were again observed to be nonmutagenic.

McGahen and Hoffman (1966) have also investigated the possible mutagenic activity of herbicides. In their program they employed a screening technique similar to that used by Andersen (described above). In their study they used both the 3- and also the 6-alkyl bromouracil herbicides (including bromacil) on a bacteriophage and concluded that it was not mutagenic by this test.

Dr. Verne Comstock (1967), U. S. Department of Agriculture and Agronomy Department at the University of Minnesota, has conducted a seven-year study on the effect of herbicide applications on the growth, yield and quality of flaxseed. During the years of 1956 to 1963 paired lines of four varieties of flaxseed were grown on plots which had received no herbicide or had received 15 to 20 oz/acre of MCPA per year (treatment was omitted in 1959). The performance of unsprayed subpopulations were compared with that of the subpopulations which had been sprayed in the F_2, F_3, and F_4 generations. "It can be concluded that the application of high rates of MCPA to successive generations did not cause a significant shift in these flax populations to more resistant biotypes."

Insect Development

Several investigators have considered the possibility that pesticides may under certain situations cause a disturbance in insect population which will result in a stimulation of a secondary pest. The reason for the increase in aphids in the grain fields in which 2,4-D amine has been used for weed control has now been investigated by Adams (1960). In her study three species of coccinellid beetles (*Coccinella transversoguttata* Fald., *Hippodamia tredecimpunctata* (L.), and *Coccinella perplexa* Muls.) were grown in the laboratory and sprayed with 2,4-D at various stages of their larval development (1 to 12 days). It was observed that spraying on the 12th day of larval development produced the highest mortality (70%) and about a 75% increase in time to maturity. Since this bettle is an important factor in the control of aphid populations on grain, weed control with herbicides should be timed so as to minimize the damage to the useful beetle.

Concentration in Food Chains

One of the big concerns of the ecologists is this, are the herbicides concentrated at some point in the food chain so that some life form at or near the top of the food pyramid will receive a toxic dose? Fortunately there are few life forms which concentrate herbicides at all and in most species this concentration is a reversible process so that the concentration level remains small. Table VI-10 shows the amount of herbicide present in the tissues of fish after exposure to the concentrations shown. For comparison it may be noted that under these same conditions heptachlor accumulates in the bluegill

TABLE VI-10

AMOUNTS OF SOME HERBICIDES MEASURED AS RESIDUES IN ANIMALS AFTER 30-DAY EXPOSURES IN PONDS

Species	Pesticide	Locality	Amount of Pesticide in Water (ppm)	Amount of Residue in Animal (ppm)
Bluegill	2,4-D PGBE in oil	Tishomingo, Okla.	10	None detected
Redear Sunfish	Silvex,* PGBE in oil	Tishomingo, Okla.	1	0.5
Rainbow Trout	Paraquat emulsion	Denver, Colo.	1	0.11
Green Sunfish	Paraquat emulsion	Denver, Colo.	1	0.05
Bluegill	Paraquat emulsion	Denver, Colo.	1	1.21
Channel Catfish	Paraquat emulsion	Denver, Colo.	1	0.37
Bluegill	Sodium arsenite	LaCrosse, Wis.	0.23	0.40
Bluegill	Diquat	LaCrosse, Wis.	1	0.09

* Fenoprop.

Source: Cope, O.B., Contamination of the Freshwater Ecosystem by Pesticides, J. Appl. Ecology, 3 (Suppl.) 33-44 (1966).

to the point where the tissue level of heptachlor is 300 times as great as the heptachlor level in water in which the fish is swimming (Cope, 1966).

Selection of Herbicides

At the present time there is no magic formula which will automatically select the herbicide which will control the vegetation best and provide the minimum damage to fish and wildlife. Instead herbicides must be carefully selected on the basis of the weed that needs to be controlled, the location of that weed, and the possible fish and wildlife which may be affected by its use. That selection of the proper formulation for the job is exceedingly important in the control of aquatic weeds without unnecessary toxic effects on the fresh-water ecosystem. In Table VI-11, the acute toxicities of a series of herbicide formulations to lake Emerald Shiners (*Notropis atherinoides*) are presented for three different exposure periods. The importance of the formulation employed is borne out by the observation that both the most toxic and the least toxic formulations are formulations of endothall and one is about 6,000 times as toxic as the other.

Spraying of Herbicides on Man

From an examination of unpublished results from the Patuxent Fish and Wildlife Center at Laurel, Maryland (Robert G. Heath, 1967), we conclude that dieldrin is at least 30 times more toxic than amitrole, atrazine, 2,4-D(BEE*), 2,4-D(DMS*), dalapon, diquat, diuron, monuron, picloram, simazine, 2,4,5-T(BEE) and 2,4,5-T acid to the two-week old young of mallards, ring-necked pheasants, bobwhite and coturnix.

One further comparison of the toxicity of herbicides and pesticides: the Federal Aviation Agency is much concerned about the toxicity of pesticides and their effect on the ability of the pilot to fly his plane safely. Dr. Paul Smith, Head of the Pharmacology Section at the Aeromedical Laboratories in Oklahoma City, said that the pilots spray insecticides during the early part of the year and then spray defoliants and herbicides in the summer for brush control. He said that the pilots themselves are always glad when they are through spraying the insecticides. He added that the flagman on the ground during the aerial spraying operation probably receives a higher dose of herbicides than the pilots. So far as he is aware there has not been a serious case of poisoning or toxicity as a result of the spraying of herbicides.

* BEE = Butoxyethyl ester; DMS = Dimethylamine salt.

TABLE VI-11

COMPARISON OF THE ACUTE TOXICITIES OF COMMERCIAL HERBICIDES TO LAKE EMERALD SHINERS (NOTROPIS ATHERINOIDES) IN MEDIUM HARD WATER. MEAN TEMPERATURE 69° - 72°F

Product	Mfr.	Liq. Gr.	Active Ingredient	TL_m, ppm active 4 hr	24 hr	48 hr	96 hr
Aquathol-Silvex	Pennsalt	L.	Endothall + Silvex	> 1,000	780	612	510
Weed Rhap 20	Reasor-Hill	Gr.	2,4-D, ethyl-hexyl ester	> 1,000	620	620	510
Amitrol T	Amchem	L.	Aminotriazole + am. thio-cyanate	910	455	455	420
Kurosal G	Dow	Gr.	Silvex, potas-sium salt	1,100	540	450	370
Crop Rider	Diam. Alk.	Gr.	2,4-D, ethyl-hexyl ester	500	280	280	280
Kurosal SL	Dow	L.	Silvex, potas-sium salt	509	420	310	270
Reglone (DB)	Chipman	L.	Diquat, di-bromide form	> 180	> 180	86.2	25.8
Reglone (DC)	Chipman	L.	Diquat, di-chloride form	> 180	15.5	11.7	9.1
Atlas A	Chipman	L.	Sodium arsenite	> 32	13.5	8.1	8.1 (As)
Esteron 99	Dow	Gr.	2,4-D, 2,4,5-T butyl esters	> 10	4.3	4.3	4.3
Garlon	Dow	L.	Dalapon + Silvex (butyl)	> 10	4.2	4.2	4.2
Urab	Allied	L.	3-phenyl-1, 1-dimethylurea trichloroacetate	5.6	4.7	4.3	3.8
Kuron	Dow	L.	Silvex, butyl ester	> 10	4.0	2.4	2.0
Hydrothol	Pennsalt	L.	Endothall, coco-amine salt	0.29	0.12	0.10	0.08

Source: Y.H. Swabey and C.F. Schenk, Proc. Third Annual Aquatic Weed Control Soc. 1963, pp. 20-28.

In summary we conclude that all of the herbicides listed in this report can be used for noncropland vegetation control with little or no danger of direct toxicity to man or animals and with the assurance that herbicides, with one or two possible exceptions, will not concentrate in any living organism to the point where they produce death in that organism or some other organism higher in the food chain. The cocoamine salt of endothall and sodium arsenite are two compounds for which measurable amounts of herbicide accumulation have been observed to occur but we have no evidence indicating that fish are killed by eating "bottom organisms" containing endothall nor has the slight accumulation of arsenic in fish tissues been shown to be an ecologic problem.

Some herbicides are toxic to fish when they are used in the control of aquatic weeds. However, experience has shown that in large lakes or streams the fish will swim away from areas where the oxygen in the water is depleted or the herbicide levels are concentrated; such a behavioral pattern would explain why fish survival in the presence of herbicides is usually greater for the field conditions than in the laboratory tanks.

The possible toxic hazards involved in the aerial spraying of herbicides in Vietnam are of concern to scientists and to the public. As mentioned elsewhere in this report the herbicides being used for defoliation of forest areas or for crop destruction are Orange (n-butyl esters of 2,4-D and 2,4,5-T), White (mixed isopropanolamine salts of 2,4-D and picloram) and Blue (cacodylic acid). After examining the voluminous toxicity data and the actual rates at which these chemicals have been applied we can make the following observations: (1) the direct toxicity hazard to people and animals on the ground is nearly nonexistent, (2) destruction of wildlife food and wildlife habitat will probably affect wildlife survival more than any direct toxic effects of the herbicides, (3) the application of Orange or White alongside of rivers and canals or even the spraying of the water area itself at the levels used for defoliation is not likely to kill the fish in the water, (4) food produced from land treated with herbicides will not be poisonous or significantly altered in nutritional quality (we use herbicides in large amounts on cropland in this country); if residues of a more persistent herbicide such as picloram should carry over to the next growing season it would retard plant growth rather than concentrate some toxic residue in the crop, (5) toxic residues of these herbicides (Orange, White and Blue) will not accumulate in the fish and meat animals to the point where man will be poisoned by them, and (6) the primary ecological change is the destruction of vegetation and the resulting ecological succession in the replacement of this vegetation.

VII. HERBICIDE RESIDUES AND THEIR PERSISTENCE

Both chemicals that are persistent and those that are rapidly decomposed are of value in the many facets of agriculture, forestry, range, and water management practice. It would be easy for the layman to conclude that persistence of herbicidal chemicals in the soil is undesirable, but that is not necessarily so. Advantage can be taken of long-term persistence in the treatment of areas where long term control of vegetation is needed in orchards, parking lots, industrial plant installations and rights-of-way. On the other hand, the accumulation and persistence of herbicidal residues in soils, vegetation and water pose certain problems or hazards, such as:

1. Injury to sensitive crops that are grown in rotation; or to subsequent natural vegetation.

2. Accumulation in foliage, seed, berries and fruit consumed as food by animals, birds, fish and man;

3. Leaching of herbicides into streams, lakes and reservoirs which would affect aquatic life and water quality for human consumption.

In this section residues and persistence of herbicides will be reviewed under the general categories of soil, vegetation and water. Emphasis will be placed on the chlorophenoxy acids, picloram, cacodylic acid, methanearsonic acid and other noncropland herbicides.

The subject of residues and persistence of herbicidal residues has been reviewed in depth by Audus (1960), Audus (1964), and Sheets and Harris (1965).

Soils

Chlorophenoxy Acids

Some of the earliest work on the persistence of chlorophenoxyacetic acids and their esters was undertaken by DeRose (1946) and Allard and DeRose (1946). DeRose and Newman (1947) made comparisons with 2,4-D, 2,4,5-T and MCPA in greenhouse and field tests. The germination of soybeans was used as a bioassay. The rates of application of compounds varied from 1 to 12.5 mg/lb of soil. In the greenhouse test, the 2,4-D persisted for 67 days and the 2,4,5-T at the 1 mg level persisted for 147 days and it was still high at 11 months. In the field evaluations, they applied from 5 to 20 lb/acre and the 2,4-D and the MCPA rapidly disappeared while the 2,4,5-T persisted for 93 days. The findings for 2,4-D were essentially the same as those reported by Newman and Thomas (1949) and Hernandez and Warren (1950) and for 2,4-D and 2,4,5-T by Newman, Thomas and Walker (1952).

Obviously, there are a number of factors that are involved in persistence and these tests indicated that the temperature and the moisture of the soil was highly important. This could be correlated with the approach to the optimal conditions for the action of soil microorganisms. The subject of the mechanisms that are involved in the reduction of herbicidal activity will be discussed in some detail in a later section.

Sheets and Harris (1965) determined that the residual phytotoxicity for 2,4-D in greenhouse tests lasted about one month, even when the rate of application was raised to 40 lb/acre. On the other hand, in field tests, a 5-lb. application persisted for 1 month. In the greenhouse 2,4,5-T persisted for one month at the 4-lb. level, but when 2,4,5-T was used in field tests at 5 lb/acre, it existed for three months.

In summary, 2,4-D, regardless of application rate, persists about one month, 2,4,5-T is more persistent in that it appears to remain in the soil up to three months. Low moisture conditions, low temperature and difference in soil types extends the period of persistence.

Picloram--(4-amino-3,5,6-trichloropicolinic acid)

Because of its persistence in soil and susceptibility to leaching, picloram has been extremely effective on deep rooted plants. However, there has been a wide variation reported in rates of loss from field and greenhouse tests. Tordon* losses range from 22 to 96% during the first year. The average loss was about 80% (Goring, Youngson, and Hamaker, 1965; Hamaker, Youngson and Goring, 1967).

It has been estimated on soil samples taken from field plots in California, South Dakota, Kansas and Minnesota that the half-life of Tordon for these various locations ranges from one to 13 months. Losses of 58 to 96 percent were sustained within one year. The application rates in these areas varied from 1.4 to 4.2 lb/acre.

In a large test representing 207 samples from 18 states, the herbicide was found in 100 of the samples. In 86% of the latter profiles, more Tordon was found in the top foot than in the second foot of soil. Only 12 samples

* Registered trademark of the Dow Chemical Company for product containing 4-amino-3,5,6-trichloropicolinic acid.

had detectable amounts below the top 2 ft. In five of these samples there was more than 20% of the herbicide remaining in the soil below the top 2 ft. However, Tordon may leach to depths as far down as 48 inches (Goring, Youngson, Hamaker, 1965). Merkle, Bovey and Hall (1966a) reported on the treatment of a thick growth of running live oak with Tordon. Only 10% of the applied material actually reached the soil. However, Tordon was detected at a depth of 24 inches within six weeks of application. No detectable residues were found in the upper 24 inches of soil after one year with rates as high as 8 lb/acre (Hamaker, Youngson and Goring, 1967).

The recovery of picloram in one season varies substantially. One pound per acre in Montana and South Dakota will yield a 50% recovery, whereas, 4-8 lb/acre in Texas yielded less than 0.1% recovery.*

The organic matter content of the soil contributes significantly to adsorption of Tordon. In a comparative study of Tordon, 2,4-D and 2,4,5-T by Hamaker et al. (1966), the following concentrations were applied: 0.94 ppm of 2,4-D; 1.34 ppm of 2,4,5-T; and 0.4 ppm of Tordon. The organic matter was adjusted over a range of 0.2 to 32.2%. The amount of these chemicals absorbed in 1 hr was approximately the same. The adsorption of picloram in soils adjusted to other than natural pH values is related to pH and varies widely from 10 to 100% at pH 2 depending upon the soil type. But the absorption at pH 8 for all soil types was quite low, 10%, except for one which was 30%. There is considerable variation in persistence of picloram as related to soil type, (Herr et al., 1966a). In light textured soils, picloram moves more completely to the lower depth (2-3 ft) than it does in heavy to medium textured soils. In the latter soil types, the chemical was still retained in the upper 6 inches, 9-15 months after surface application.

In summary, picloram, depending upon soil type, may penetrate to depths of 2-4 ft. In other soils of heavier texture with high organic matter, it tends to stay in the upper 6 inches. As much as 80% of the picloram application may disappear within one year.

Cacodylic Acid (dimethylarsinic acid) and Methanearsonic Acid

It is well known that the inorganic arsenicals that have been used for years in horticulture practices have a tendency to accumulate to a high degree. An impressive example is given by Sheets and Harris (1965) in their review of a paper by Jones and Hatch (1937), who reported that as much as 3,500 lb/acre of lead arsenate was sprayed on an apple orchard over a 25-year period. Usually, arsenate or arsenic residue in this form remains largely in the top 6-8 inches of soil.

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* Personal Communication from Dr. Keith Barrons of the Dow Chemical Company.

There is a difficulty in estimating the build-up of arsenic in soils by herbicide application. Natural occurring arsenic is always present in the analyzed sample. The common method for arsenic analysis, according to Ehman (1965) is a drastic oxidation procedure. The organic matter is converted to water and carbon dioxide and the organic arsenicals are oxidized to the inorganic ortho arsenic acid, which in turn is chemically reduced to the very reactive arsine. A colorimetric procedure with high sensitivity can be used on arsine.

Literature sources concerning cacodylic acid and methanearsonic acid are extremely limited.

Ehman and Birdsall (1963) studied the adsorption of cacodylic acid on pasture sod. They sprayed the sod (4 ft x 4 ft x 10 inches) with 3.81 g of Ansul's Ansar 138, containing 65% cacodylic acid and 0.85 g of Emulphor 620 surfactant. The sods were watered with about 1/2 inch of rainfall at one, two and four weeks. Some of the sod clay samples leached arsenic in the first 24 hours. In general, the cacodylic acid was strongly bound to the clay, silt loam and sand sods. After one week, the cacodylic acid became evenly distributed throughout a 10-inch depth.

Ehman (1965) found that when an amount of disodium methanearsonate (DSMA) equivalent to 28 lb/acre was applied to the top of a soil column which was leached with 60 inches of water, less than 10% of the applied DSMA showed up in the leachate. When sandy loam was used in the soil column, the figure was less than 6%. In a similar experiment performed with 15 lb/acre of cacodylic acid, and using an extrapolation to 60 inches of leaching water, about 9% leached through the sand column and 6% for the sandy loam. It is evident that DSMA and cacodylic acid are largely inactivated by the soil.

Other Herbicides

Sheets and Harris (1965) have gathered together an impressive collection of information concerning the residual phytotoxicity of herbicides which is shown in Table VII-1. The herbicides, 2,4-D, TCA, and dalapon disappear rather rapidly from the soil (Behrens, 1962). They seldom persist more than a month or six weeks when they are used at the recommended levels of weed control. Other herbicides such as monuron, atrazine and simazine sometimes persist into the following growing season. Considerable amounts of EPTC, atrazine and simazine may be absorbed in soils with a high moisture content. Light inactivates some herbicides such as diuron, monuron and 2,4-D (Weldon and Timmons, 1961), diquat and paraquat (Funderburk et al., 1966; Funderburk and Bozarth, 1967). Also, chemical decomposition may occur at elevated temperatures, dalapon being an example.

TABLE VII-1

PERSISTENCE OF VARIOUS HERBICIDES IN SOIL

Herbicide	References	Field (F) or Green-house (G)	Lb/Acre[a]	Residual Phyto-toxicity (months)
Amitrole	Rangel (1959), Sandford and Stovell (1960)	F	3-18	1-3
	Neururer (1962)	F	8.9	4-5
Atrazine	Switzer and Rauser (1960), Neururer (1961), Swader and Fletchall (1962)	F	2-4	4-7
	Behrens (1959), Neururer (1962), Harris and Sheets (1965)	F	2-3	4-7
	Meggitt (1964), Wisk and Cole (1965)	F	3-8	12
	Sheets et al. (1962), Sheets and Shaw (1963)	G	3.2-4	4-8
Dalapon	Sweet et al. (1958), Sandford and Stovell (1960)	F	7.4-20	1
	Neururer (1962)	F	20	3-4
	Warren (1954), Kaufman (1964)	G	6-8	1-2
Diuron	Hollingsworth (1955), Weldon and Timmons (1961), Neururer (1962)	F	3.6-4	5-7
	Hill et al. (1955)	F	1-2	4-8
	Weldon and Timmons (1961a)	F	2	15
Fenac	Robinson (1961), Harris and Sheets (1965)	F	4-5	12
Monuron	Hollingsworth (1955), Shadbolt et al. (1964)	F	2-4	5-6
	Switzer and Rauser (1960), Webster (1962)	F	4-6	12
	Loustalot et al. (1953), Ogle and Warren (1954), Warren (1954)	G	2-5	1-3
Endothall	Comes et al. (1961)	G	6	1
	Switzer and Rauser (1960)	F	12	1

TABLE VII-1 (Concluded)

Herbicide	References	Field (F) or Green-house (G)	Lb/Acre[a]	Residual Phyto-toxicity (months)
Simazine	Fletchall (1958), Sweet et al. (1958) Behrens and Thompson (1960), Stroube and Bondarenko (1960), Switzer and Rauser (1960), Swader and Fletchall (1962)	F	2-5	12
	Detroux (1957), Aelbers and Homburg (1959), Neururer (1962)	F	0.45-4.5	3-7
	Webster (1962)	F	4	18
	Sheets et al. (1962), Sheets and Shaw (1963)	G	3.2-4.0	4-14
TCA	Rai and Hamner (1953), Ogle and Warren (1954), Warren (1954)	G	8-60	1-3
	Robinson and Dunham (1949), Neururer (1962)	F	12.5-67	7-12
	Arakeri and Dunham (1950), Loustalot and Ferrer (1950b)	F	16-30	4
2,3,6-TBA	Phillips (1959), Webster (1962)	F	15-20	12-32
	Dewey and Pfeiffer (1959), Robinson (1961)	F	3-4	5-12

a/ Rates originally reported in ppm were multiplied by 2 to give pounds per acre.

Source: Sheets, T. J., and C. J. Harris, Herbicide residues in soils and their phytotoxicities to crops grown in rotations. pp. 123-124 from Residue Reviews, 11 F. A. Gunther (Ed.), Springer-Verlag, New York, Inc., 1965.

A comparison of the relative persistence of some selected herbicides in the soil is shown in Figure VII-1 and Table VII-2. This information was derived from Audus' review (1964). There is reason (data of Sheets and Harris, 1965) to question simazine's position in the figure; more accurately it should be indicated as having a position at the bottom of the chart.

Sheets and Harris (1965) have reported that dalapon applications ranging from 2 to 15 lb/acre are residual in the soil for one to three months as measured by phytotoxicity. Day et al. (1963) reported that in 43 soils dalapon disappearance varied from complete in less than two weeks to retention of two-thirds of the added dalapon after eight weeks.

Sheets (1964) has reviewed the disappearance of substituted urea herbicides from soil and comparative studies are discussed concerning monuron, diuron and fenuron.

Weldon and Timmons (1961) worked with diuron, applying it after the first cutting of alfalfa, and used oats in a bioassay. They sampled their test plots at three, seven, and 15 months. The herbicide was found to be localized in the top 1/2 inch of the soil and it did not go below 4 inches in depth. Repeated treatments persisted in about the same manner as the original applications. Diuron applications of 3 to 4 lb/acre last five to seven months and applications of monuron, ranging from 2 to 6 lb/acre varied all the way from one to 12 months (Sheets and Harris, 1965).

Crafts and Drever (1960) conducted a study on a number of herbicides, including monuron, using the oat plant as the sensing agent. Monuron was very persistent, even after 20 runs each of which included a 30-day growing period and a 30-day drying period. Toxicity was acute above 12.8 ppmw in two soils and above 25.6 ppmw in another soil.

Amitrole has been reported to persist from one to five months based on residual phytotoxicity tests (refer to Table VII-1).

Amitrole becomes highly absorbed to soil particles, as indicated by Sund's (1956) work with soils having an exchange capacity of 29.5 meq/100 g soil or more. He also reported 50 % of 3-amino-1,2,4-triazole was decomposed in three weeks when applied to four soil types having a wide range of sand and silt.

Bondarenko (1958) conducted radioisotope studies on the breakdown of amitrole. He found that the rate of evolution of $C^{14}O_2$ reached a maximum in 13 days and decreased rapidly until the 42nd day and thus the decomposition decreased gradually until the 240th day at which time the rate of evolution of $C^{14}O_2$ was extremely slow.

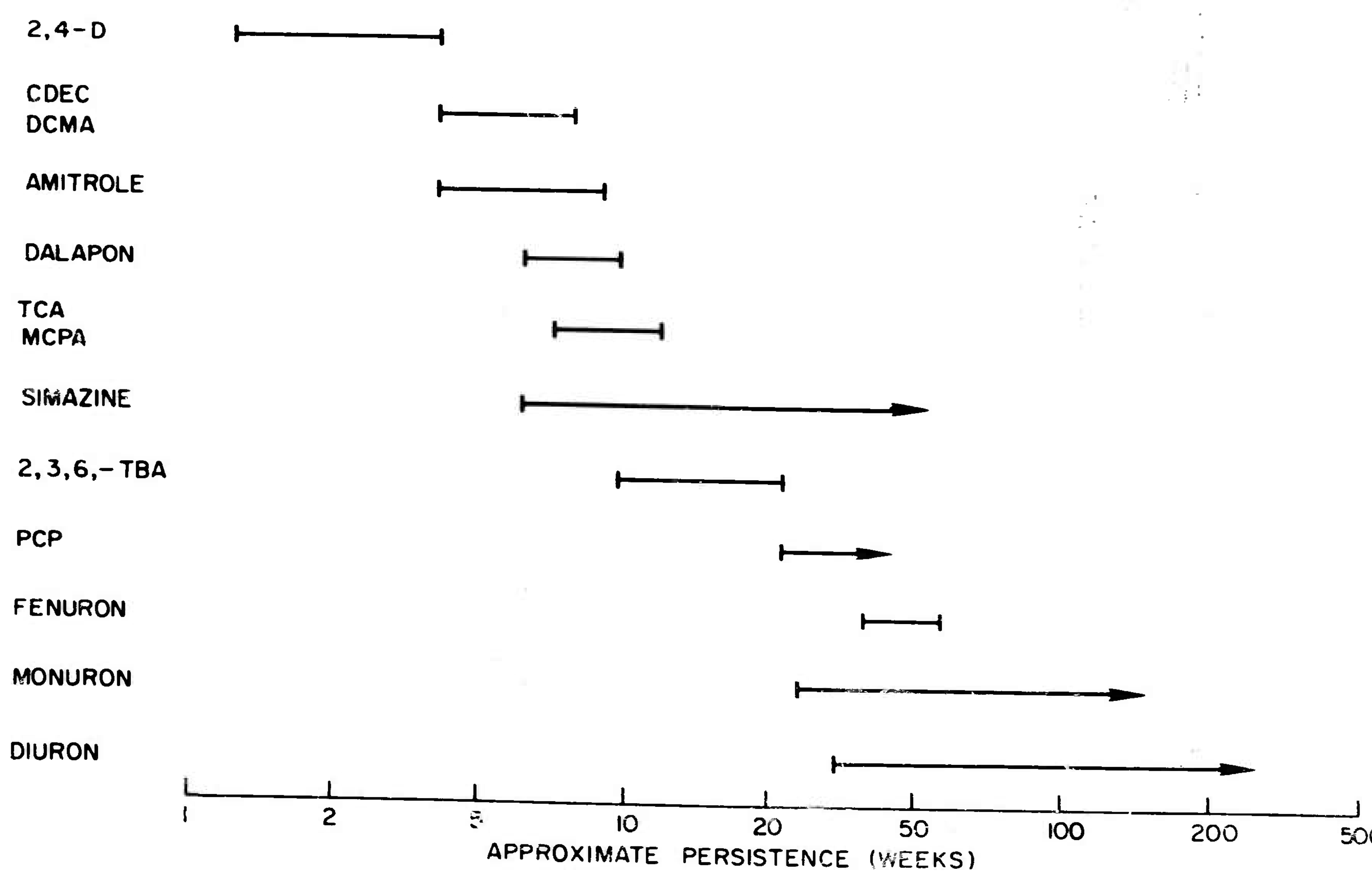

Figure VII-1 - Relative Persistence of Various Herbicides in the Soil

TABLE VII-2

PERSISTENCE OF HERBICIDES IN A MOIST LOAM FIELD SOIL, WITH LITTLE OR NO LEACHING, UNDER SUMMER-TIME TEMPERATURES IN A TEMPERATE CLIMATE

Chemical	Rate per Acre	Type of Treatment	Persistence in Time
Simazine	10-40 lbs.	Soil Sterilant	6-24 months
Fenuron	4-40 lbs.	Soil Sterilant	3-12 months
Monuron	20-50 lbs.	Soil Sterilant	6-20 months
Diuron	10-40 lbs.	Soil Sterilant	6-24 months
Sodium chlorate	450-1,200 lbs.	Soil Sterilant	6-12 months
Arsenic	750-1,000 lbs. (As_2O_3 equiv.)	Soil Sterilant	6-24 months
Boron	1,000-3,000 lbs. (B_2O_3 equiv.)	Soil Sterilant	6-24 months

Source: Klingman, G. C., Weed Control: As a Science, p. 66, John Wiley and Sons, Inc., New York - London (1961).

Simazine applied at the rate of 2 to 5 lb/acre persisted for 12 months, while other investigators reported persistence up to 18 months. Persistence of TCA applied at the rates of 4 to 67 lb. varied all the way from 1 to 12 months (Sheets and Harris, 1965).

One of the most persistent compounds is 2,3,6-TBA with applications running from 15 to 20 lb., lasting from 12 to 32 months. Stubs (1960) has reported that diquat is almost completely absorbed to soil and unavailable to plants, and probably paraquat undergoes the same reaction. This is explained in that both of these compounds form divalent cations in solution and strong negative interactions with negative-charged soil particles are to be expected.

TCA, the sodium salt of trichloroacetic acid, causes a temporary soil sterility that lasts from 40 to 108 days, depending upon the soil (Rai and Hamner, 1954).

Fenuron is used to control a variety of woody plants in forests and other noncultivated areas. In tests made by Shipman (1967) using 5 and 10 lb/acre, no fenuron residues were found after 5 months within an 8 inch depth in sandy loam soil, at the 5 lb. level. In the silty clay loam, 60% persisted. At the higher application level, 10 lb/acre, 14 and 43% were detected in the sandy loam and silty clay loam, respectively.

Hill et al. (1955) concluded that residue carry-over, even after continuous use, is small under most climatic and edaphic conditions, the rates of disappearance of monuron, diuron, atrazine, simazine and related herbicides equal or exceed 80% per year. In other words, when herbicidal applications of 2 lb/acre are repeated on the same soil each year, and 80% of this residue disappears, the maximum residue in 12 months after application approaches 1/2 lb/acre.

Sheets and Harris (1965) were of the opinion that massive accumulation of herbicides was highly unlikely. One must bear in mind that this statement is in regard to the levels commonly used in agricultural practice. However, accumulation can occur in agricultural lands that receive repeated dosages of herbicides. Some chemicals, such as 2,3,6-TBA, atrazine and fenac have a tendency to leach down to depths of 2 ft or more. More research is needed in the decomposition of the herbicides that have moved down to greater soil depths.

Forest litter retention of herbicides is of importance in problems of runoff to streams or lakes. This is especially so if the reservoir or sources of water are for human consumption. Of lesser importance, but having ecological significance is the possible effect on wildlife and aquatic vegetation and fish.

Norris (1966) and Norris and Greiner (1967) have reported some studies of persistence of 2,4-D and 2,4,5-T in forest litter when triethanol amine salts of labeled 2,4-D and 2,4,5-T were applied in water to the surface of the litter at a rate of 2 lb. acid equivalent per acre. The following observations were made--percent degradation as measured by radioactive CO_2 liberation:

	315 Hr	690 Hr
2,4-D	89%	--
2,4,5-T	23%	53%

Norris felt that the slower rate of decomposition of the 2,4,5-T may have been due to a lag in accommodation of microorganisms to the chemical.

In another study, forest litter was selected from five types of forest trees: Douglas fir, big leaf maple, vine maple, Ceanothus and red alder. These litter samples were treated with 3 lb/acre equivalent of (1) 2,4-D acid, (2) triethanolamine salt, (3) isooctyl ester, (4) isooctyl ester plus 1 lb/acre of DDT or (5) isooctyl ester plus 4 gal/acre diesel oil. In 15 days, the recovery of 2,4-D applied as the salt varied from 60 to 75% for all the types of litter. The esters persist longer than the acid, 65% vs. 55%. The addition of lb. of DDT/acre seemed to stimulate herbicidal degradation.

Vegetation

Herbicide applications for crop lands can be divided into three types: (1) pre-plating, (2) pre-emergence, (3) post-emergence. A number of factors have to be considered in the selection of an herbicide for a specific crop use: weed specificity, fairly rapid dissipation and minimum residue carry-over when crops are rotated. Certainly, weather conditions have an effect on herbicide dissipation and the tolerance of the primary and the succeeding crop to possible soil residues, enters into the picture.

Chlorophenoxy Acids

Crafts (1964) has summarized the literature on the metabolsim of the phenoxy acids in plants. Some specific examples taken from this review are as follows: 2,4-D is not freely mobile in the plant; therefore, it is not easily translocated to the roots (Crafts, 1959). In addition, 2,4-D is readily oxidized in plant tissues.

Luckwill and Lloyd-Jones (1960 a,b) worked with the metabolism of 2,4-D in berries. Red currant oxidized up to 50% of the carboxyl and 20%

of the ethylene carbon of 2,4-D when it was supplied to the leaves for seven days through cut petioles. In contrast, the black currant is susceptible to 2,4-D, oxidizing only 2% of the chemical under the same conditions. The red currants were able to metabolize 2,4,5-T, 4 CPA and MCPA.

The Cox apple variety is resistant, decarboxylating 50% of the applied 2,4-D in 92 hours. Brambleys seedling apple, metabolized about 2%. It has been reported that stored lemons in which 2,4-D had been added to the wax, contain ester-like residues (Erickson et al., 1963). In a study with oranges, Erickson and Hield (1962) found that orange trees sprayed with 20 ppm of 2,4-D contained an average of 0.1 ppm of 2,4-D one day after spraying.

Fewer studies have been conducted on woody plants. Morton (1966) studied the absorption and distribution of 2,4,5-T in mesquite (Prosopis juliflora var. glandulosa (TORR) Cockerel) seedlings. Absorption took place throughout a 72-hr period. At 72 hr, the recovery of absorbed 2,4,5-T as measured by radioisotope techniques, from all untreated tissues was 12, 13 and 3% at 70, 85 and 100°F, respectively. The distribution and residue of labeled 2,4,5-T in red maple and white ash has been investigated by Leonard et al. (1966). When 2,4,5-T ester or amine is applied to leaves of these species, 30 days after treatment 96-99% of the C^{14} was found in the leaf laminas. When these compounds were applied to bark (stem) the 2,4,5-T amine was translated less than the ester form. The ester in amounts of up to 24%, moved to the leaf laminas.

2,4-D is especially harmful to dicotyledonous plants: tomatoes, cotton and some legumes. It has been reported by Monroe (1964) that 1 oz of 2,4-D distributed over 35 acres of cotton will seriously injure the crop. This work was done by Dunlap and Engle (1949) at the Texas Agricultural Experimental Station.

Legume crops, while not as sensitive as cotton, are generally receptive to 2,4-D action. Four pounds per acre will kill ladino, white clover and lespedeza. The tolerance of peanuts to 2,4-D is generally 1-1/2 lb/acre. Soybeans seem to be tolerant to 2,4-D up to 2 lb/acre. Rice tolerates 1/2 lb/acre. Pasture plants tolerate 1 lb/acre and sorghum is tolerant to 1-1/2 lb/acre. When soybeans are treated with 1/2 to 1 lb/acre of the amine formulation of 2,4-D, the mature seed will accumulate and retain a small residue of 2,4-D (Szabo, 1965).

Monroe (1964) also reported on some unusual observations occurring after 2,4-D treatment. Corn treated with 2,4-D becomes more palatable for field mice and sheep will eat Centaurea Salstitialis only after it is sprayed with 2,4-D.

There have been a few reports of residues in pasture grasses that are related to the transfer to the milk of cows grazing on these crops. Pastures have been sprayed since 1945 and in 1962 over 4 million acres were sprayed with various amine salt and ester formulations of 2,4-D. Klingman et al. (1966) found that residues in pasture grasses sprayed with the butyl ester of 2,4-D disappeared more rapidly than in those from pastures sprayed with 2-ethylhexyl ester. Virtually all of the butyl ester of 2,4-D is hydrolyzed to the acid within 1/2 hr after spraying. This is contrasted to 12 ppm of residue remaining after spraying with the 2-ethylhexyl ester of 2,4-D, and appreciable amounts persisted for seven days. The transfer of 2,4-D to milk is insignificant. Residues less than 0.01 ppm, 2,4-D in milk would be found if dairy cows are not pastured for seven days after spraying with the butyl or 2-ethylhexyl ester of 2,4-D.

Picloram--(4-amino-3,5,6-trichloropicolinic acid)

The effectiveness of Tordon herbicide in controlling deep rooted perennial broad leaf plants has been substantiated by several workers (Alley 1965, Friesen 1964, Warden 1964). Tordon is a persistent material. Herr and associates (1966b) applied Tordon to two different types of seed beds at the rates of 2, 4, 8, 32, and 64 oz/acre. This application was made in the month of September. In the following spring, all plots were reworked and single row plots of corn, spring oats, spring barley, alfalfa and soybeans were planted. With corn there was no visible effect from any application rate up to and including 32 oz/acre. There was some reduction in height at the 64 oz/acre level. In oats there were no effects for any rate up to and including 32 oz. At 64 oz the stands were reduced about 25 to 30%. Barley reacted with deformation of the heads and awns at the 4 oz/acre level. There was a 25% reduction in the stand occurring at 8 oz and there was a 98% reduction in stand and no heads were developed at 64 oz. Alfalfa was very sensitive in that a stand reduction of 5 to 10% occurred at 4 oz and reached 50% at 8 oz. There was no reduction in the soybean stands that had been treated with Tordon herbicide at rates up to and including 8 oz/acre. Ninety-five percent of the plants were eliminated however, on all plots that had previously been treated with 32 oz/acre. The tolerances of the crops tested were corn> oats > barley > alfalfa and equal to soybeans.

Some work has been done on Tordon residues in cereal grains, Bjerke et al. (1967). Samples were taken from many locations having several methods of spraying in winter wheat and barley. The samples were obtained from plots of grain treated with post emergence herbicide application at growth stages ranging from three leaf to completely tillered.

With Tordon 202,* Tordon 303,** and Tordon 22K***weed killer (WK), the application rates ran from 1/2 to 1 oz/acre but most of the applications would average around 3/8 oz/acre. Sixty-eight of the 91 samples contained less than 0.05 ppm of residue. Greater amounts of residue were found in some samples treated at the higher application rates and these residues ran to 0.22 ppm in wheat grain, 0.44 ppm in wheat straw and 0.64 ppm in barley grain. In another field test Alley and Lee (1967) treated a heavily infested field of Canada thistle with various rates of picloram and dicamba. Treated areas were planted to barley in 1965 and cross seeded to several crops in the spring of 1966 (22 months after the initial treatment). All the crops grew well in the dicamba treated areas. These crops included barley, oats, wheat, sorghum, clover, alfalfa, soybeans, field beans and corn. Only the grass crops, barley, oats, wheat, corn and sorghum grew in the picloram treated plots. Sweet clover, alfalfa, soybeans and field beans were killed at all rates of application.

The first paper concerning the metabolism of picloram in plant and soil was reported by Merkle et al. (1966). These workers found picloram in cotton plants which had been exposed to picloram in the soil. They felt that the picloram was combined with the protein and no other radioactive entity was present. The distribution of the radioactivity indicated that 95% of the herbicide was associated with the leaf and the stem and only 5% remained in the roots.

Cacodylic Acid (dimethylarsinic acid) and Methanearsonic Acid

Cacodylic acid, methanearsonic acid and their salts have extremely low vapor pressures. They are contact type, post-emergence herbicides. Ehman (1965) has reported that when pasture lands are treated with 5 lb. of cacodylic acid, and planted to alfalfa and rye grass within three days after treatment, growth was not inhibited and cuttings from these two crops did not show arsenic residues. In standard practice when 5 to 10 lb/acre of DSMA is used in the soil for weed control, no residues have been found in cotton and cotton rotational crops or in several orchard fruits after an inactivation time of one month or less.

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* Tordon 202 contains 1.4% of 4-amino-5,5,6-trichloropicolinic acid and 22.1% of 2,4-dichlorophenoxyacetic acid as the triisopropanol amine salt.

** Tordon 303 contains 1.35% of 4-amino-3,5,6-trichloropicolinic acid and 21.5% of 2-methyl-4-chlorophenoxyacetic acid as the potassium salt.

***Tordon 22K weed killer contains 2 lb/gal of 4-amino-3,5,6-trichloropicolinic acid as the potassium salt.

An interesting experiment was conducted with high levels of cacodylic acid to simulate a buildup. Experimental plots were treated with 37.5 lb/acre. The application was made on May 1. Cotton, soybeans, sorghum and peanuts were stunted severely. The peanuts had to be replanted on May 29. At harvest time, soybeans had developed normally and the seed did not contain arsenic residue. The cotton, sorghum and peanuts were stunted, the yields were down and the seed and hay had arsenic residues present.

Ehman (1965) reported on the effect of high levels of DSMA (disodium methanearsonate) applications to soil on cotton, soybeans, sorghum and peanuts. The DSMA was applied at rates of 9.5, 31.5, and 63 lb/acre (equivalent to 2, 7, and 14 years of use in cotton, two applications of 2.25 lb/acre/year). When cotton, soybeans, sorghum and peanuts were planted on the day of treatment, only the peanuts had to be replanted. The second planting of peanuts and the original planting of cotton, soybeans and sorghum, all developed normally. There was some slight stunting at the 63 lb/acre level in the early stages of growth. All high samples showed arsenic residue from 0.29 to 3.64 ppm for treated samples (controls 0.10 to 0.18 ppm). Peanuts and sorghum grain contained low residues at the 9-1/2 lb/acre rate. At the high rates residues varied from 0.52 to 3.12 ppm. Cotton seed contained residues at the 31.5 and 63 lb/acre rates. There were no arsenic residues in the soybeans from any of the plots.

Ehman (1965) found that when a combination of 10 lb/acre of cacodylic acid and 10 lb. of DSMA were used, in grapefruit orchards, no residues could be found in the fruit. In soil build-up tests, utilizing 15, 22, 41, and 79 lb/acre of DSMA, no arsenic residues were found in grapefruit.

Ehman and Birdsall (1963) reported on a study that involved the residual effects of cacodylic acid on beans, potatoes, carrots, cabbage, corn and soybeans. The test plots were sprayed with 1 gal of a cacodylic acid solution. The treatment was equivalent to 5 lb/acre of pure cacodylic acid. The plots were planted five days later. Over a period of one month 8.9 inches of rainfall was applied. The increase in soil arsenic by analysis was 3 ppm at a 3 inch depth. The authors stated, "There was no significant pickup of arsenic by edible crops in the treated plots." Unfortunately, no data for control plots were presented.

A few studies have been conducted on organic arsenic residues in grasses (Long et al. 1962; Lucas, 1964). A wide range in arsenic residue on coastal bermuda grass has been found (Searcy and Patterson, 1964; McBee et al., 1967). When calcium acid methanearsonate (CAM) was applied at the rate of 5 lb. of arsenic per acre, the arsenic content went from 114 ppm at five days to 5 ppm at 33 days. In comparison monosodium acid methanearsonate (MSMA) at the same application level fell from 1921 ppm at seven days to 38.9

at 36 days. Disodium methanearsonate (DSMA) (4 lb. of arsenic per acre) was more persistent. The amount of arsenic fell from 475.2 ppm at five days to 101.8 ppm at 33 days.

Other Herbicides

Sheets and Harris (1965) indicated in a summary of their article that cereals planted in the fall after crops that have received some application of diuron, atrazine, simazine, diphenamid and some related herbicides are subject to damage. There has been trouble with the use of atrazine on corn, in that damage has occurred 10 to 12 months after application for soybeans, sugarbeets, oats and forage grasses and legumes. Sometimes in continuous cropping, high levels of herbicides may be used because the primary crop itself is highly resistant; an example being the application of simazine and triazine in maize. The weeds such as Agropyronrapens need 5 lb. of simazine per acre to be killed, and this high application can be made without affecting the corn.

Fenac residues sometimes persist from one to two years and the planting of tobacco, cotton, peanuts and soybeans after corn has resulted in damage.

Amitrole has been found to be a useful herbicide in sugar cane fields and along irrigation ditch banks. Hilton and Uyehara (1966) have studied the residues in sugar cane treated with 10, 20 and 40 lb/acre. The application was made in two sites, one having a rainfall of 50 inches, the other 150 inches/year. The amitrole disappeared from the sugar cane in eight weeks after an application of 40 lb. of chemical.

The persistence in soils of twenty-nine s-triazines has been investigated by Sheets and Shaw (1963). The evaluation was carried out with corn, grain, sorghum, soybeans, cotton and crabgrass, using the herbicide as a subsurface preemergent. Cotton was used as a test crop for the post-emergence study.

The utilization of monuron in citrus orchards or asparagus planting and simazine in lawns is advantageous in those cases where the danger occurs only when the cropping system is changed. In the Western European countries, autumn applications of 2,2-dichloropropionic acid (dalapon) and trichloroacetic acid are recommended for the control of perennial grass weeds. There is sufficient retention in the winter months to prevent the growing of grasses in the cereal in the following spring. However, problems may develop when the moisture content or unusually dry times retard the loss.

Water

Chlorophenoxy Acids

One of the real problems from the standpoint of the effect of herbicide residues and the persistence of these residues in the ecosystem involves water supplies for human consumption. Watersheds and drainage from cropped areas that have been treated with herbicides might in turn result in secondary effects involving the health of domestic animals, wildlife or aquatic life. Nicholson and Thoman (1965) have estimated that the present population depending upon surface streams for drinking water in 1960 was about 100,000,000 which was up 15% over 1940. It is estimated by 1980 that the population depending upon surface water would be about 165,000,000 out of 200,000,000. With increasing use of herbicides on noncropland, it is important to evaluate their persistence in surface water. Most of the work that has been reported has been concerned with the phenoxyacetic acids and their esters, paraquat, diquat, silvex and amitrole.

Faust, Tucker and Aly (1961) and Faust and Aly (1963) investigated the effect of 2,4-D and 2,4-dichlorophenol (2,4-DCP) on drinking water quality. 2,4-DCP can occur as a formulation impurity or as a product of chemical or biological degradation of 2,4-D in surface water. At concentrations less than 8 μg/liter and 2 μg/liter, respectively, chlorinated phenols impart objectionable medicinal taste and odors to water. They found levels of 2,4-DCP ranging from 70 to 4500 μg/g of formulation. In laboratory carboy studies with lake water, using two granular forms of 2,4-D, 9.5 and 16.7 μg/liter of 2,4-DCP were released in seven days. Maximum concentrations of 14.7 and 20.7 μg/liter were observed at 148 and 218 days. In other carboy tests, they found that the phenol disappeared rapidly under conditions of neutral and stable pH values, aerations and small amounts of organic matter. About 40 to 50% of 2,4-dichlorophenol can persist up to 80 days under conditions of acid pH and anaerobic surface water unfavorable for biological oxidation. They suggested that there was a possibility of three mechanisms being responsible for the release of free phenols from 2,4-D and 2,4,5-TP herbicides: "(1) a free phenol impurity present in the formulation as a result of manufacturing process, (2) chemical hydrolysis of the organic ester in water, (3) biological degradation of the ester portion of the herbicides."

Cochrane et al. (1967) evaluated the persistence of Kuron.* When the herbicide was applied to the surface water at the rate of 8 lb. equivalent acid per acre, they obtained a rapid hydrolysis of the esters to silvex acid. Silvex acid gradually diminished in concentrations and traces remained for at least 19 weeks. These authors recommended that silvex should not be applied to a body of water that is being used as a source of water for human consumption.

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* 64.5% propylene glycol butyl ether esters of silvex equal to 42.8% silvex acid equivalent.

Since surface water accounts for most of the municipal water supplies, our attention is drawn to the spraying of forest lands over watersheds with herbicides. According to Shepherd et al. (1966), about 71 million acres in the U. S. were sprayed with weed control chemicals in 1962. About 4% of the total acres thus treated, or 2.5 million acres was forest and range land. Tarrant and Norris* (1967) have pointed out that about 100,000,000 acres of commercial forest land at the present are either nonstocked or poorly stocked with trees of acceptable quality or species. However, these forests received about one-half the total precipitation and yield about three-fourths of the total stream flow. Most forest lands annually receive an average of 45 inches of precipitation, which is about twice that which falls on other lands, and forest lands yield about 20 inches of run-off, which is almost seven times that of other lands.

Periodic sampling in Oregon revealed only a light and short-lived contamination of stream water as a result of aerial spraying of 2,4-D and 2,4,5-T. In a test reported by Gratekowski et al. (1965) and Tarrant and Norris (1967) detectable quantities of herbicides were found in virtually all streams sampled after 2,4-D, 2,4,5-T or a 1 to 1 mixture of 2,4-D and 2,4,5-T low volatile esters in diesel oil were applied at the rates of about 2 lb/acre from a helicopter. The quantities found range from 0.2 ppb to 70 ppb. Usually in a matter of days, the level fell to 0.2 ppb. Maximum variation from checkpoint to checkpoint was a total disappearance of 2,4-D in two days and at another, 17 days. Krammes and Willets (1964) reported on the spraying of sprouted vegetation after a watershed was cleared with equal parts of 2,4-D and 2,4,5-T in diesel oil. They used 88 gal of herbicides (concentration of acid equivalent wasn't reported) in this application and later they stump-sprayed with 45 gal of herbicide. They took samples over a five-month period; all samples were below 1 ppm and no trace of diesel oil was found. In another study, brush was sprayed by helicopter to try to convert vegetation on a steep side slope from brush to grass. They applied 3/4 gal of 3 lb. acid equivalent each of low volatile esters of 2,4-D and 2,4,5-T in 1 gal of diesel oil and 17-1/2 gal of water. They used 20 gal of this mixture per acre. As a follow-up treatment, they hand sprayed the brush with a herbicide mixture of 1/2 gal of 2 lb. acid equivalent each of 2,4-D and 2,4,5-T in 1 gal of diesel oil and 98 gal of water. They sampled the surface water at weirs and for all practical purposes, no herbicides were found. In sampling the soil, they detected small amounts of herbicides at 8 days. There were no herbicides present a month and a half after initial spraying.

When 2,4-D and 2,4,5-T combinations were used in a 1 to 1 basis and at the rate of 2 lb/acre, in 9-1/2 gal of diesel oil, there is no effect upon salmon fry or on stream bottom organisms (Tarrant and Norris, 1967).

* Unpublished information.

Evidently diesel oil used in the sprays is not a source of trouble. Norris cites work by Linden and Muller (1963), who applied diesel oil at rates in excess of 50, 250, and 500 gal/acre, which was followed by leaching with 100 ml of rainwater and only 1.5 to 2 ppm of diesel oil were found in sandy loam at a depth below 2-1/2 inches. These investigators felt that the application of diesel oil to the soil surface at rates of more than 50 gal/acre presented no threat to ground water quality.

The water hyacinth is a pest in southern streams and a considerable amount of work has been done in removing these plants by mechanical and chemical methods. There is a great deal of interest in the persistence of herbicides in these waters because of the possibility of carry-over into the Gulf Coast areas which support shell fish life.

Averitt (1967) investigated the rates of disappearance of 2,4-D acid equivalent dispersed at 4 lb/acre by injecting the herbicide into the propeller wash of a small motor boat. On the first day, the concentration was about 689 ppb and had fallen on the fourth day to 80 ppb. The decline thereon was rather slow until the 31st day, when it had dropped to 10 ppb. They also conducted some tests in plastic boxes with applications of 5 lb/acre of 2,4-D. Twenty-two days were required for the concentration to drop from a high on the seventh day of 972 ppb to 11 ppb. Aly and Faust (1964) made studies of the decomposition or persistence of 2,4-D residues in hydrosoils. When the herbicide was added to lake bottom soil that had been treated previously with 2,4-D, the herbicide decomposed at 35 days. When 2,4-D was added to untreated lake hydrosoil, the decomposition time was 65 days. Frank and Comes (1967) worked with granular 2,4-D (20%). The herbicide persisted longer in the hydrosoil than in the water, but it could not be detected after 55 days.

A study of the effect of 2,4-D treated irrigation water on red Mexican beans has been reported by Bruns (1951). When herbicide at 2 lb/acre in the water was applied to beans in the seedling stage, the root systems were severely attacked. Within 16 days the plants began to recover. When the level was raised to 6 lb/acre, the yield was reduced 40%. When these levels of application were made in the bloom stage, the 2-lb. level caused no significant reduction in yield. The loss at 6 lb. was 29%. Frank and Comes (1967) introduced 1.33 ppm of 2,4-D into a pond; one day after treatment the concentration was 0.024 ppm. The maximum, 0.067 ppm, occurred on the 18th day and fell to 0.019 ppm by the 24th day.

Picloram and Cacodylic Acid

A search of the scientific literature has not revealed any reported studies that have been conducted on cacodylic acid or picloram residues or their persistence in a water environment. Some information exists on sunlight studies of picloram degradation in water.* Concentrations of Tordon ranging from 1 to 67 ppm and solution depths ranging from 12 ft. to 0.1 inch have given rates of degradation ranging from approximately 0.04 to 0.5 lb. of Tordon/acre/day. Decomposition appears to be accomplished by wavelengths below 300 mμ. At low concentrations, herbicide rates of decomposition appear to increase with increased depth of water. The quantitative relationship is not yet known. The rate of decomposition in deep water is more rapid when the water is circulating than when it is calm. However, this is not true for shallow water. The results of tests in various geographical locations indicate the variability of light degradation caused by sunshine in water is about threefold.

Although it is not directly related, a report by Frank et al. (1963) indicated that cacodylic acid was inactive on submerged aquatic weeds.

Other Herbicides

Diquat (1,1'-ethylene-2,2'dipyridylium dibromide) and paraquat (1,1'-dimethyl 4,4'-dipyridylium dichloride) are commonly used herbicides for pond and lake treatment, since they are quite effective on aquatic vegetation and at the same time relatively non-toxic to fish.

Blackburn and Weldon (1963) and Coates et al. (1964) reported persistence of diquat for eight and 11 days.

Grzenda et al. (1966) found that paraquat persisted in ponds from six to 23 days and diquat fell from 0.81 on the first day to 0.01 ppm on the seventh day. In another pond, the concentration fell from 1.25 ppm on the first day to 0.08 ppm on the ninth day and down to 0.01 on the 27th day.

Frank and Comes'(1967) work supports the findings of the other workers reported above. In addition, these investigators studied the persistence of endothal. When the compound is dispersed in water at the rate of 1 ppm, it persists in the same time reference as paraquat and diquat. It was detected up to 24 days in the water. Frank (1966) studied the persistence of monuron in soil and water. Appreciable losses do not occur for 8 to 16 weeks after application. At the end of one week, 29% of the monuron was recovered from the first inch of soil. Fifteen percent of the monuron remained in the soil after 128 weeks.

Diquat and paraquat will persist in hydrosoils for long periods of time. Beasley et al. (1965) found 1.2 to 7.9 ppm of paraquat and a trace to 1.7 ppm of diquat persisting in hydrosoils where the pools had been treated four years previously with 0.3 lb/surface acre.

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* Personal communication from Dr. Keith Barrons of the Dow Chemical Company.

Frank and Comes (1967) applied 1.14 ppm and 0.62 ppm of paraquat and diquat to ponds, and found that both chemicals still persisted in the hydrosoils 160 days after treatment.

Grzenda et al. (1966) examined the persistence of 3-amino-1,2,4-triazole (3AT) and the sodium salt of fenac (2,3,6-trichlorophenylacetic acid). The ponds were treated with one of the herbicides in August of 1962 and retreated with diquat and paraquat in late November. Concentrations of 1.0 to 4.0 ppm were used. Fenac persisted in the water at about 5.2 ppm from the first day and was reduced to 2.4 ppm on the 202nd day. The level of 3-aminotriazole in the pond water was 1.34 ppm on the first day and was down to 0.5 on the 68th day; the content was still 0.13 ppm on the 154th day. Obviously, fenac appears to have the least potential for use in sources of potable water because of its long survival.

Tarrant and Norris (1967) also investigated amitrole as an herbicide in studies in Western Oregon for two successive years. Amitrole is an effective chemical for controlling hard to kill salmon berry (Rubus spectabilis Pursh). Spraying was accomplished by helicopter using 2 lb/acre in 10 gal of water. The levels of amitrole in stream water at the spray site decreased 100-fold from 400 ppb in samples taken 5 min after spraying to 4 ppb after 10 hr. Amitrole was not detected after three days. In another test with amitrole, Norris et al. (1967) treated 260 acres with 2 lb of amitrole-T per acre and no quantities of amitrole were detected between three and 150 days after treatment. Stream water that contained 42 and 45 ppb at the end of 6 hr was down to 5 and 9 ppb, and the reserve totally disappeared in 48 hr.

Summary

The persistence of a herbicide in the soil depends upon a number of factors, which include its chemical composition, rate of application, type of soil-leaching characteristics, and receptivity to degradation by soil microorganisms and climatic conditions, such as rainfall, temperature, and exposure to sunlight.

In this summary of the residence time of the various herbicides in soil, vegetation and water, the data shown are largely those values for soil retention that one would expect to find under conditions of average rainfall and within the average temperature ranges common to the United States. Furthermore, the reader should bear in mind that depending on the herbicide the residues may be sufficiently phytotoxic to affect the next crop in rotation, or they may be bound tightly to the soil particles and not active against plant root systems.

Persistence of Herbicides in the Soil

2,4-D and 2,4,5-T are not considered to be persistent herbicides. The residence time of 2,4-D and 2,4,5-T is about one and three months, respectively. 2,4-D in amounts of 20 lb/acre usually disappears in two months.

Picloram is persistent in the soil. About 80% disappears within the first year. The half life, depending upon edaphic and other environmental conditions, will range from 1 to 13 months. In one instance the amount present after a 27 lb/acre application of picloram was ten times higher than at a 9 lb/acre level. In low rainfall area (8 to 10 inches) picloram (8 lb/acre) has been found on the surface of the soil 26 weeks later. Picloram residues leach readily and have been found at a depth of 5 ft. It is not uncommon for this herbicide to leach to a depth of 24 inches in three months.

Cacodylic acid and disodium methanearsonate are tightly bound to soil. Cacodylic acid applied to sod becomes rather evenly distributed at a 10-inch depth in about one week.

Diuron and monuron at the 4 lb/acre level persist for 5 to 8 months. At the soil sterilant level of application (40 to 50 lb/acre) the residues will remain 6 to 24 months.

Atrazine at 4 lb/acre level persists 4 to 7 months. Simazine at this level is more persistent, ranging from 7 to 18 months. Paraquat and fenac persist up to a year. 2,3,6-TBA is highly persistent (5 to 32 months) at application rates of 3 to 20 lb. TCA and dalapon residues disappear rapidly (1 to 3 months).

Residues that may affect crops in rotation are picloram, atrazine, simazine, diuron, monuron, fenac and 2,3,6-TBA.

Persistence of Herbicides in Vegetation

There is very little information on the persistence of the chlorophenoxyacetic acids on or in vegetation. 2,4-D is very short-lived. The 2-ethylhexyl ester may persist a week. The butyl ester hydrolyzes in 30 min after spraying. In one variety of fruits 50% is oxidized in 92 hr. In another variety only 2% is degraded in the same time interval.

Picloram in combination with salts and esters of 2,4-D or 2-methyl-4-chlorophenoxyacetic acid applied at the rates of 0.5 to 1 oz/acre produced a residue in two-thirds of the grain samples of less than 0.05 ppm. The higher application rates raised the residual picloram up to 0.22 ppm and 0.64 ppm in wheat and barley grain, respectively. Picloram is one of the most nontoxic herbicides to animal organisms.

Alfalfa and rye grass have been planted three days after applying 5 lb/acre of cacodylic acid to the soil, and no carry-over of arsenic was found in the crops at harvest. No arsenic residues were found in beans, potatoes, carrots, corn, cabbage, and soybean grain grown on soil treated with 5 lb. of cacodylic acid. Application of 10 lb. of cacodylic acid and 10 lb. of disodium methanearsonate (DSMA) together in soils in grapefruit orchards did not produce arsenic residues in the fruit.

In order to produce arsenic residues in peanuts, sorghum and soybean hays, the levels of application of DSMA have to be elevated to 31½ and 63 lb/acre. These levels of application are equivalent to the amounts of the herbicide applied to cotton over a seven- and 14-year period.

A high level of 37½ lb/acre (2.5 lb/acre twice a year normal application on cotton) of cacodylic acid will produce arsenic residues in cottonseed, sorghum grain, and peanuts. The soybeans, hay and seed were free of arsenic.

There is practically no information on residues from atrazine, dalapon, fenac and trichloroacetic acid in vegetation. Amitrole at the 40 lb/acre level will appear in the stalks of sugarcane for a very short period of eight days.

Persistence of Herbicides in Water

2,4-D is degraded rapidly in surface water in amounts of 5 and 5 lb/acre. By 30 days it degrades to levels of 10 ppb starting with levels as high as 1,000 ppb. When 2 lb/acre of 2,4,5-T or 2,4-D and 2,4,5-T low volatile ester mixtures are sprayed by helicopter, it can be detected in ppb in stream waters, but its persistence is in terms of days.

Silvex at 8 lb. acid equivalent per acre rapidly hydrolyzes and silvex acid may persist as long as five months in the water. It is not recommended for application to drinking water sources.

Dichlorophenol (DCP) may occur as a by-product in some commercial lots of 2,4-D. It imparts a medicinal taste and odor to water at levels of 8 µg and 2 µg/liter, respectively. It may persist for 10 to 200 days depending upon water conditions (pH, aeration, etc.).

2,4-D, 2,4,5-T combinations applied at the rate of 2 lb/acre have no effect on salmon fry or bottom stream organisms. If the hydrosoils have previously contained 2,4-D, a subsequent application will be degraded in about 30 days. Hydrosoils not previously subject to 2,4-D may require 60 days to degrade.

There is practically no information on the persistence of picloram and cacodylic acid in water. There is one paper suggesting that picloram is degraded rapidly by light, ranging from 0.04 to 0.4 of a lb. of picloram per acre per day.

Amitrole and amitrole-T at 2 lb/acre cannot be detected after three days.

Diquat and paraquat will persist in water for a week. However, these compounds can be detected in the hydrosoils for as long as four years after treatment of the water has taken place. The compounds are inactive, tightly bound to the bottom soil particles.

Endothall has about the same persistence in water as paraquat and diquat.

VIII. SOME FACTORS DETERMINING THE FATE OF HERBICIDES

Several factors are known to determine the fate of herbicides in soil. These may include decomposition by microorganisms, leaching, temperature and photochemical alterations which will be included in this review. There are other processes that enter into the picture, such as adsorption, volatilization, chemical reactions and absorption and metabolism by the plant.

Role of Microorganisms

The wide range of herbicide persistence in soil is mainly related to their susceptibility to chemical decomposition. One of the factors contributing to their destruction is the action of soil microorganisms. This field of investigation has been pursued by a host of workers since the late 1940's. The previous section devoted to residues and persistence of the herbicides in soils reflects in many instances the results of the action of microorganisms which were responsible for the destruction of the herbicide.

Audus (1964) has reviewed the evidence for microorganism breakdown, relationship of chemical structure to ease of attack by microorganisms and the biochemical pathways of herbicide degradation. In addition, he as well as Newman and Downing (1958) reviewed the effects of herbicides on soil microorganisms.

Chlorophenoxy Acids

The literature on the breakdown of the chlorophenoxy acids by microorganisms is voluminous. The most commonly studied herbicide in this group is 2,4-D. Early investigators concerned with persistence as related to moisture, temperature and autoclaving, include DeRose and Newman (1947); Newman and Norman (1947); Brown and Mitchell (1948). Kries (1947) studied the effects of water organic matter and lime on persistence. Martin (1946) was the first to investigate the decomposition of 2,4-D in soil from the standpoint of microbial action. DeRose and Newman (1947) were the first to report that the rates of application did not affect the persistence of either 2,4-D or 2,4,5-T; also, that 2,4,5-T persisted longer than 2,4-D. Increased moisture levels in the soil led to high rates of decomposition whereas persistence varied inversely with soil temperature (range 10° to 30°C). These investigators, as well as Newman and Thomas (1949), pointed out that the autoclaving of soils did not bring about any detectable decrease in 2,4-D biological activity. Soil profusion techniques indicated that the decomposition of 2,4-D was due almost entirely to soil microorganism (Audus, 1949).

Newman and Thomas (1949) and Audus (1949) observed that there was a time lag before the rapid decomposition phase of 2,4-D began. Audus (1964) gave the phenomenon of bacterial proliferation in response to a new substrate the term "enrichment." This investigator points out that once the state of enrichment is attained, the quality is retained for long periods of time after the herbicide is decomposed. Enriched soils stored moist can retain the enriched state for a period of one year. When soil columns were percolated continuously for 11 to 60 days, the microorganisms still were able to decompose 2,4-D at a much faster rate than fresh soil.

A number of the microorganisms have been identified that attack herbicides. Audus (1951) made the first isolation of a bacteria (Bacterium (arthrobacter) globiform group) from enriched soil that was grown on agar with 2,4-D as the sole source of carbon.

Since that date, a number of workers have isolated organisms that attack herbicides. A list of the organisms and the herbicides they are known to attack are shown in Tables A-3 and A-4 of the Appendix.

Picloram (4-amino-3,5,6-trichloropicolinic acid)

There is very little information concerning the action of microorganisms on picloram. The first report on the subject was made by Meihle et al. (1966). Carboxyl-labeled 4-amino-3,5,6-trichloropicolinic acid was used in the studies. The evolution of $C^{14}O_2$ in microcuries/15 days x 10^4 equaled 24 for plant, 50 for bare soil and 326 for soil containing plants or the relative decomposition rates were 1:2:26. After 15 days, the $C^{14}O_2$ evolution increased abruptly and then leveled off. No explanation was given for this phenomenon. A comparative study of the effects of 2,4-D and picloram has been made on a specific strain of Aspergillus Niger V.T. (Arnold et al. (1966)). Levels of 0, 0.4, 2, 10 and 50 ppmw were used in the culture studies. 2,4-D significantly reduced growth of A. Niger at concentrations of 10 and 50 ppmw in cultural media. Growth depression of A. Niger was not apparent with picloram. Highly significant decreases in bean plant growth were obtained with all herbicide levels. As a follow-up on Arnold's et al. (1966) study, Goring and associates (1967) tested the effect of picloram on 45 common organisms. The incubation studies were for one day, one week and one month. Picloram at concentrations of 1,000 ppm did not seem to have significant gross effect on the fungi and bacterial population of the soil. Doses as high as 1,000 ppm in soil did not appear to significantly affect CO_2 evolution, urea hydrolysis or gross counts of bacteria and fungi.

Cacodylic Acid (dimethylarsenic acid) Methanearsonic Acid

Information on the decomposition of cacodylic acid or the other organic arsenicals used as herbicides is meager. Cacodylic acid is highly residual in the soil in that it is tightly bound to soil particles. Challenger (1947) made a comprehensive review of the action of the mold Scopulariopisis brevicaulis (Penicillium brevicaule). This mold will produce $(CH_3)As$ from As_2O_3 and sodium cacodylate. It has been reported (Zabel and O'Neil, 1957) that cacodylic acid and disodium methylarsonate have a low activity for inhibiting the growth of Bacillus mycoides, Aerobacter aerogenes, penicillium expansium, and Aspergillus Niger. Methylarsenic acid has some inhibiting activity on Bacillus mycoides but very little activity on the other bacteria and molds described above. The same low activity for inhibition was also shown for zinc, lead, bismuth, sodium, potassium, magnesium, iron, calcium and barium salts of cacodylic acid.

Other Herbicides

The Weed Society of America has recently published information on the microbial breakdown of a large number of herbicides in commercial use (Herbicide Handbook, 1967). Reference may be made to information on selected herbicides in the Appendix, Table A-5.

Sund (1956) indicated that the ultimate breakdown of amitrole (3-amino-1,2,4-triazole) was due to microbiological attack. Day et al. (1961) and Ercegovich and Frear (1964) found that the rates of decomposition of amitrole in steam-sterilized soil was much lower than in unsterilized soils, indicating that decomposition is primarily due to the action of microorganisms.

Burschel and Freed (1959) found that at 29°C all of the amitrole disappeared from the soil by the seventh week, and it had fallen from its original concentration to 50% within four weeks. Ercegovich and Frear (1964) studied the rate of recovery of 3-amino-1,2,4-triazole from Hagerstown silt loam soil, as a function of temperature, pH, soil moisture and microbial activity. There was a direct correlation between soil moisture and the persistence of amitrole. At the end of six days, 58% of the added amitrole was recovered from air-dried soil. In the same length of time, only 8% was recovered from soil containing 15% moisture and none from soil containing 30% moisture. Riepma (1962) examined the decomposition of amitrole as a function of absorption on the soil, pH, temperature and organic matter. In one study, he applied 60 ppm of amitrole to four soil types. Practically all the amitrole had disappeared within 65 days from one soil type (pH 7.1) containing 36.6% clay and 4.5% organic matter. In contrast, another soil (pH 5.0) containing 8.8% clay and only 1.5% organic matter decomposed amitrole slowly (80 days, 75 down to 40 ppm). Macrae and Alexander (1965) reported that amitrole is readily attacked microbially since essentially the same quantity of tagged CO_2 is found after one week as after 16 weeks.

Atrazine and simazine are adsorbed to certain soil constituents. Even with continuous application for years, atrazine is rarely found below 12 inches in the soil. The greater portion of simazine will be found in the upper two inches of soil. Simazine has a low water solubility. The decomposition of s-triazine herbicides by soil microorganism has been studied by several investigators (Reed 1960; Burnside et al. 1961; Kaufman et al. 1963, 1965).

Kaufman et al. (1965) developed a population of soil microorganisms that effectively degraded simazine by using enrichment techniques. They found that degradation would begin immediately, but it continued very slowly in that only 3 to 4% was degraded in 30 days. One organism, Aspergillus fermigatus Fres., could degrade simazine almost completely in 12 days. Burschel (1961) reported that simazine was degraded in about 135 days to less than 10% of its original concentration at a temperature of 25°C. At 18°C a soil containing 1% humus was degraded about 50% in 150 days; and in a soil containing 10% humus, decomposition had taken place to about 85% in 170 days. In contrast to simazine, 2,3,6-TBA adsorption does not increase as readily with organic matter content (Phillips, 1959; Burnside, 1953a).

Chandra et al. (1960) examined the effects of high concentrations of simazine on microorganism activity in nine Oregon soils. This study was conducted concurrently on EPTC, diuron, and 2,3,6-TBA. Seventy-two treatments were evaluated by carbon dioxide evolution methods. The 72 treatments included nine soils, four herbicides and two treatment levels, 5 and 100 ppm. The 100-ppm level is 20 to 35 times normal rate--field practice. Although there were obvious differences between soils in their response, the herbicides in most cases depressed carbon dioxide evolution for at least 28 days. For only two treatments was the depression significantly greater at 56 days. The authors felt the decrease in effect after 28 days could indicate (1) acquirement of microbial tolerance for the herbicides, (2) their decomposition, or (3) their possible inactivation by adsorption on organic matter or clay. In most instances, the depression of carbon dioxide evolution was greater with the 100-ppm level than at the 5-ppm level. Diuron showed different interactions with the different soil types at either rate, it appeared to depress carbon dioxide production most at 14 days. In a few instances, notably with simazine in two soil types at seven and 14 days, carbon dioxide evolution was temporarily increased 12 to 14% by herbicide treatment at the 5-ppm level. Higher rates of the herbicides did not inhibit in proportion to the concentrations applied to the different soils.

Kratochvil (1951) studied the effect of TCA (10, 50, 100, 150 lb. per acre) and endothall (1, 2, 4, and 8 lb. per acre) on soil microorganism activity. All the rates were calculated on the active ingredient basis. The technique used involved the placing of soil treated with the chemicals in 250 Erlenmeyer flasks. Water content was adjusted to 35% by weight. At the end of 48 hr of incubation, the flasks were closed and incubation continued for 4 hr. At the end of that period, the pressure that had developed in the flasks was measured by a mercury manometer. Gas was generated by all levels of TCA; however, none of the pressures were as high as that generated on the check sample. Ten pounds per acre of TCA give a reading of about 7 cm of mercury, while the 150 lb. per acre level of TCA produced only 2 cm of mercury pressure. The measurement of microbial decomposition with endothall was a considerably different picture: the levels of 1, 2, and 4 lb. exceeded the check sample, and 8 lb. only slightly depressed the pressure below that of the check sample.

Temperature

Temperature has an effect on the persistence of herbicide residues and on the response of vegetation to herbicide treatment.

The effect of temperature as a factor in herbicide decomposition in soil is exerted in two ways (1) directly, as related to chemical decomposition, dalapon would be an example; and (2) indirectly, as it affects the activity of the soil microorganisms that are capable of using the herbicide as a source of energy.

Chlorophenoxy Acids

Some of the early work that was done on the effect of temperature upon the inactivation of 2,4-dichlorophenoxyacetic acid in the soil was conducted by Brown and Mitchell (1948). They used concentrations varying from 3.5 to 174 mg (equivalent to about 100 lb. per acre) of 2,4-D per pound of soil. Using mustard and barley as indicators, they found the survival rate to be 5% at 36°F, 30% at 50°F and 50% at 70°F. The same trends with temperature variation were observed by Hernandez and Warren (1950). These investigators conducted greenhouse experiments with 2,4-D (70% dichlorophenoxyacetic acid equivalent). The fresh weight of cabbage plants was used as a criterion of the residual toxicity of the 2,4-D in the soil. Three groups of potted cabbage plants were utilized, and one-half of each group was treated with the equivalent of 4 lb. of 2,4-D per acre. The pots were stored at 40°, 59° and 65° to 90°F. The 2,4-D in the soils, stored at 59°F and 65° to 90°F were inactivated after four weeks. At 40°F, the 2,4-D was still toxic at the end of eight weeks and completely inactivated after 12 weeks.

The type of soil as well as differences in temperature as they affect 2,4-D decomposition was examined by Ogle and Warren (1954). The 2,4-D application rates were 2 and 4 lb. per acre, respectively. The treated soils were placed in dishes in temperature chambers at 8°, 12°, 25° and 35°C. In general, the disappearance of 2,4-D was proportional to the temperature. Breakdown was more rapid in silt loam than in sandy soils and most rapid in muck. 2,4-D at 4 lb. per acre disappeared rapidly in the muck soil, one week at 18° and 25° and four weeks at 8° and 35°.

Barrier and Loomis (1957) and Rice (1948) have shown that raising the temperature from 15°C to 30°C resulted in increased uptake of 2,4-D by beans and soybeans.

Muzik and Mauldin (1964) investigated the effects of temperature on the growth susceptibility of 2,4-D at various growth stages and the effect of translocation of 2,4-D. Their test plants were peas and tomatoes (temperature-sensitive crops) and winter wheat and fiddleneck (Amsinckia intermedia) (temperature-resistant crops).

When the fiddleneck had one leaf dipped in 250 ppm of 2,4-D solution, the plant showed only slight response to 2,4-D when grown at 5°C; at higher temperatures, that is 10°C, 20°C, the 2,4-D caused severe malformation.

The tomato plant's root and stem growth was much more seriously inhibited at 20° and 30°C than at 10°C. In another study with tomato plants maintained at 55°F the visible response of a plant to 2,4-D was inhibited. However, the plant contained the 2,4-D since the herbicidal symptoms were visible when the temperature was raised (Muzik, 1965).

The response of mesquite seedlings (prosopis joliflora var. glandolosa (Torr.) cockerel) to 2,4,5-T is greatly dependant upon temperature. Over a 72-hr period, no significant differences were found in the amount of 2,4,5-T absorbed by the leaves at 70° and 85°F. After 72 hr, an increase occurred at 100°F. However, at the higher temperature translocation is limited to a short distance acropetal. Metabolism rates are best at 70° and 85°F, completely inhibited at 50°F and lower at the higher temperature 100°F (Morton, 1966).

<u>Picloram (4-amino-3,5,6-trichloropicolinic acid)</u>

The decomposition of picloram has been studied (Youngson et al., 1967) over a temperature range of 34° to 95°F, utilizing two soil types designated as A and B. The composition of soil types A and B were as follows:

	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	pH
Type A	59	35	6	1.5	5.7
Type B	29	43	28	3.2	6.2

The results of this study are shown in Table VIII-1. As indicated, 10- to 25-fold increases in rate of decomposition were obtained by increasing the temperature from 35° to 94°F.

TABLE VIII-1

DECOMPOSITION OF 4-AMINO-3,5,6-TRICHLOROPICOLINIC ACID AT VARIOUS TEMPERATURES IN 71 DAYS

Soil[a]	Soil Moisture As a Percent of Water Holding Capacity	Temp. (°F)	Micromoles of Carboxyl Carbon Evolved from Herbicide (A) $\times 10^4$	Micromoles of Carbon Evolved from Soil (B) $\times 10^{-2}$	Estimated Decomposition of Herbicide (%)
A	68.6	34-36	15.5	13.1	0.78
		64-70	111	23.8	5.59
		93-95	444	42.5	22.3
B	42.2	34-36	15.5	16.6	0.78
		64-70	108	33.9	5.43
		93-95	161	58.6	8.10

a/ Containing 0.96 ppm of herbicide.

Cacodylic acid (dimethylarsinic acid and methanearsonic acid)

Rumburg et al. (1960) observed the effect of temperature on the herbicidal activity in translocation of arsenicals. These studies were conducted in controlled environmental chambers using crabgrass as a test species. The experiments were conducted at 60°, 75° and 85°F. The rates of application for DSMA were 0, 2, 6 and 18 lb. per acre cacodylic acid at 0, 1, 3 and 9 lb. per acre, and sodium arsenite (on the basis of As_2O_3) at 0, 0.5, 1.5 and

4.5 lb. per acre. Utilizing the dry weight of crabgrass, 10 days after application, as a measure, there was less growth at 85°F than at 60°F. As one would expect, the amount of growth declined with the increasing rates of DSMA applied. In another test, utilizing application rates of 5, 10 and 15 lb. per acre of DSMA, growth was greatly retarded at 90°F over 60°F. It was not possible in these tests to arrive at any conclusions concerning the effect of temperature on the herbicidal activity of sodium arsenite or cacodylic acid.

Gallager and Beatty (1965) reported that several workers had found disodium methylarsonate (DSMA) to be more active when applied during periods of high temperatures.

Other Herbicides

Evidently, amitrole depletion from the soil is a biological function. Day et al. (1961) studied the effect of soil temperature on the rate of decomposition of amitrole by Vista and Chino soil. The initial application of amitrole was 20 mg per 100-g sample of soil. Analysis was made at four-day intervals on samples maintained at 10°, 20°, 30° and 40°C. There was considerable variability in the breakdown of amitrole between the Vista sandy loam and the Chino silt loam. However, the rates of decomposition at 10° and 40°C were parallel and roughly fell from 80% to 85% in 24 days, to 55% to 65%. The degradation in the Vista sandy loam at 20° to 30°C was much more rapid (about 90% in 16 days). In comparison at the 20° and 30°C temperatures, in the Chino silt loam, the recovery was about 40% in 24 days. From these data the 20° to 30°C range is more near the optimum for degradation .

Results from the laboratories of Burschel and Freed (1959) and Riepma (1962) showed the same trends as reported by Day et al. (1961). Burschel and Freed (1959) worked with 15° and 29°C temperatures using an original concentration of 20 ppm. The amitrole dropped to 30% of the original concentration by six weeks at the 29°C temperature, whereas 48% of it was retained at 15°C.

Riepma (1962) studied a broad range of factors (concentration,pH, microbiological toxicity and organic matter) that influenced the breakdown of amitrole. He found that increase in soil organic matter and temperatures up to 30°C increased the degree of microbial attack.

Temperature has an effect on the persistence of 3-amino-1,2,4-triazole in plants. Muzik (1964) found that the herbicide persisted in the plant for 100 days at 70° and 85°F when applied to a single leaf (excised after one week). Plants held at 55°F one month or more following the 3-amino-1,2,4-triazole application were killed,while plants at 70° or 85°F recovered.

The fate and activity of TCA in the soil has been observed by Ogle and Warren (1954). The herbicide was mixed uniformly (8 lb.per acre) in the soil and placed in dishes in temperature chambers at 8°, 18°, 25° and 35°C. They were maintained moist through the course of the experiment. In sandy soil, relatively little breakdown of TCA was observed; the loss was proportional to the temperature. Much more breakdown occurred in silt loam and especially in muck; here again dissipation was the function of the temperature.

Leaching from Soils

Chlorophenoxy Acids

A review of adsorption and desorption of organic pesticides by soil colloids has been prepared by Bailey and White (1964). This paper presents the rates of soil reaction, soil type,physico-chemical nature of the pesticide exchange site, soil moisture, nature of formulation and temperature that influence the adsorption of pesticide by soil colloids.

Hartley (1960) discussed the physico-chemical aspects of the availability of herbicides in soil. He stated that the leaching of herbicides is affected by the solubility and the adsorption of the herbicides in the soil, the moisture level of the soil at the time of application, and the amount of evaporation. Wiese and Davis (1964) studied the movement of dimethylamine salts of 2,4,6-trichlorobenzoic acid (2,3,6-TBA), polychlorobenzoic acid (PBA), the amine salt of 2,4-dichlorophenoxyacetic acid (2,4-D), the sodium salt of 2,3,6-trichlorophenylacetic acid (fenac), ester of fenac, 3-phenyl-1,1-dimethylurea (fenuron), 3-(p-chlorophenyl)-1,1-dimethylurea (monuron), the amine salts of 2-(2,4,5-trichlorophenoxyl) propionic acid (silvex) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). The above herbicides were applied in water solutions or suspensions to tubes of soil. The leaching rates were as follows:

	Depth of Leaching (inches)
Dimethylamine salts of 2,3,6-TBA and TBA	18 and 19-1/2
Amine salt of 2,4-D and sodium salt of fenac	15
Ester formulation of fenac, fenuron amine salt of silvex amine salt of 2,4,5-T monuron	9
2,4,5-T 2,4-D silvex	3

In general there was a relationship between the depths of movement in the tubes and the solubility of the herbicides, except for perhaps the amine salt formulation of 2,4,5-T and silvex. Other studies have been performed utilizing the tube technique (Hattingh, 1958). 2,4-D amine salt was applied at the rate of 2 lb. acid equivalent per acre on seven soil types. A given amount of rain was applied and the study confirmed that the greatest movement occurred in the light sandy soils. A considerable movement occurred in granular types of clay soils. Further studies were undertaken using three formulations of herbicide on four sandy soils and one granular type. 2,4-D amine salt and 2,4-D isopropyl ester were compared, and there was virtually no difference in their pattern. 2,4-D ester, a 2,4-D amine salt, 2,4-D acid amide, 2,4-D acid and MCPA potassium salt and an MCPA acid were compared at three levels of rainfall, 1/2, 1 and 2 inches, using Koppies* soil. Surprisingly, the acids and the 2,4-D acid amide, although relatively insoluble, moved appreciably.

<u>Picloram (4-amino-3,5,6-trichloropicolinic acid)</u>

Hamaker and associates (1963) compared the leaching rates of 2,4-D, 2,4,5-T and picloram. These three chemicals were applied to the top of columns containing sandy silt loam at the rate of about 100 lb. acid equivalent per acre. These columns were leached with 2, 4 and 8 inches of water. They used radish plants as an indicator and found that in all cases, columns leached with 2 inches of water, produced symptoms in the radishes to a depth of 12 inches or more. When they were leached with 8 inches of water, the chemicals were moved so far down the column that no symptoms were observed in the radish plant until a depth of at least 10 to 12 inches. It would appear from these tests that picloram is like 2,4-D and 2,4,5-T in that it is easily leached under high rainfall conditions.

Herr and associates (1966) obtained a broader view of the leaching capacity in picloram using a wider range of soil characteristics, silty clay, a silt loam light-textured, and a silt loam medium-textured.

Surface applications of picloram were made on plots at the rates of 0, 2, 4, 8, 32 and 64 oz. per acre at each location. The amount of precipitation that occurred from the time picloram application was made, to the sampling of the silt loam soil, was 2.5 inches, 15.8 inches and 26.7 inches, respectively. Corresponding data on the light-textured silt loam were 2.3 inches, 24.9 inches and 41.8 inches. The amount of precipitation that occurred in the medium-textured silt loam during these periods was 1.9 inches, 27.3 inches and 45.9 inches. In the silty clay soil at the 280-day level, the amounts of picloram in the first 6 inches of soil was about one-half of that obtained on the 101st day for the 2, 4 and 8 oz. per acre treatment. For the 64 oz. per acre treatment, at the end of 476 days, there was still a high concentration

* African soil type.

in the first 18 inches and most of it was in the top 6 inches. The results on the light-textured silt loam indicated that for the 2, 4, 8, 32 and 64 oz. levels by the end of 245 days, that a considerable amount of leaching had taken place down to the 24-inch level. On the medium-textured silt loam, much more of the picloram had leached out of the upper levels at 2, 4, and 8 oz. applications per acre than on the silty clay. However, at the high levels, 64 oz. per acre, at least one-third of the original amount in the first 6 inches was still present and amounts up to 78 ppb had leached down to the 30-inch depth. The data indicated that picloram residues moved faster and more completely in the lighter texture of soil with a low organic content. This trend is also reported by Goring and associates (1965). Substantial amounts of picloram were found more than 430 days after application of 32 and 64 oz. per acre on all three soils, indicating residues from larger applications were quite persistent.

In several locations picloram has been found at depths of 2.5 to 3 ft, and in two locations it has been detected at depths of 4.5 to 5 ft.*

Tschirley (1967) studied the leaching rates of picloram in two types of soil (Houston clay and Axtell sandy loam) and sand using the soil column technique. One gram of potassium salt of picloram was applied uniformly to the top surface of the soil. The soils were moistened to field capacity. Water equivalent to 1 inch of rain was dripped onto the soil over a period of 1 hr and samples were taken at various depths of 1, 4 and 24 hr. After 1 hr, simulated rain had moved the picloram 12 to 24 inches in sand. After 24 hr, the herbicide was concentrated at the lower depths. Picloram moved to a depth of only 2-1/2 inches at 0.1 field capacity and 6 to 12 inches at field capacity in Houston clay. Movement in Axtell sandy loam was 6 to 12 inches at 0.1 field capacity and 12 to 24 inches at field capacity. The column experiments were compared with field plots. The plots were 5 x 5 ft and were treated with 1 lb. per acre of picloram. Water was added equivalent to 1 inch of rain in 1 hr. After 24 hr, the picloram content was 0.95, 0.78 and 0.04 ppm at 0-1, 1-3 and 3-6 inches, respectively. No picloram was detected below the 6-inch level, which correlated with the results in the Houston clay.

Tschirley (1967) conducted herbicide leaching studies on three soil types in Puerto Rico, Jacona clay (Guanica Commonwealth Forest), Nipe clay (Maricao Commonwealth Forest), Los Guineos clay loam (Luquillo National Forest). These soils were described as:

* Personal communication from Dr. Keith Barrons, Dow Chemical Company.

Jacona clay - alluvial soil, low permeability

Nipe clay - permeable, well-drained, lateritic soil

Los Guineos - clay loam plastic clay, poor internal drainage

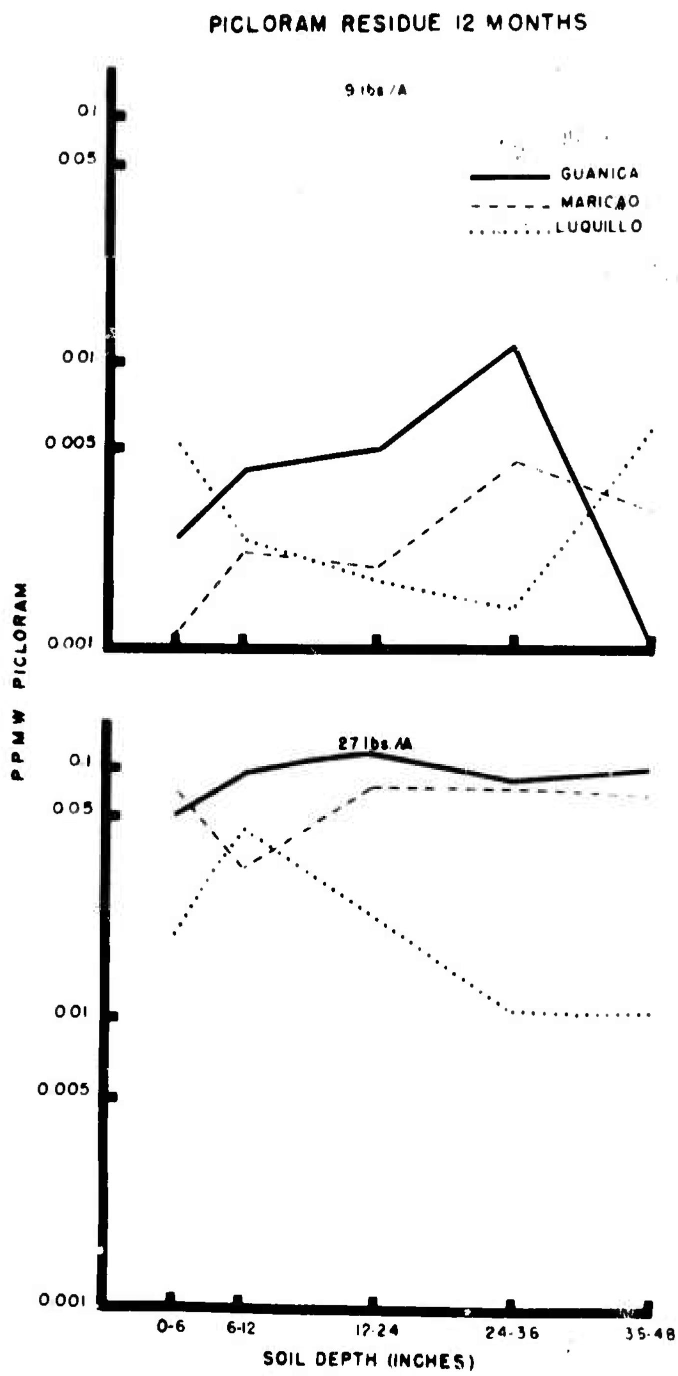
The recorded rainfall was:

	Rainfall	
	1964	1965
Guanica Commonwealth Forest	27.9	25
Maricao Commonwealth Forest	84.6	109.9
Luquillo National Forest	85.5	126

Picloram was applied at the rates of 3, 9 and 27 lb. per acre. The soils were sampled at 3, 6 and 12 months. Soil samples were taken in the following depth ranges: 0-6, 6-12, 12-24, 24-36 and 36-48 inches. Three months after application, picloram moved downward in the soil to the 36- to 48-inch depth. One year after application, the residue of picloram in plots treated with 27 lb. per acre remained at a constant relatively high level, at all test sites (Figure VIII-1). The presence of picloram in plots treated with 9 lb. per acre could be easily detected one year after treatment, but the concentrations were about 10 times lower.

At the same time the picloram was evaluated, bromacil, dicamba, diuron, fenac and prometene were subjected to the same regimen. All of these herbicides moved downward in the soil to the 36- to 48-inch depth. The persistence of the herbicides in the soil for one year after treatment was in the order fenac > prometene > picloram > diuron > bromacil > dicamba.

Other studies were conducted by Tschirley (1967) in Texas on the leaching of picloram. The soil types were used at the Victoria site; the soil was a Katy gravelly loam with a variable amount of gravel in the lower profile. At College Station, the soil was an Axtell fine sandy loam. Picloram was applied at the rates of 2 and 8 lb. per acre from a boom about 15 ft above the brush. Observations made immediately after spraying indicated that approximately 25% of the picloram reached the soil surface at the College Station site, and 10% reached the soil surface at the Victoria site. The latter was virtually covered with live oak. At College Station no detectable residue was present in the surface soil after 12 weeks, even at the 6-lb. per acre rate; and within two weeks most of the picloram had moved to a depth of 6 inches.



Source: F. H. Tschirley, Response of tropical and subtropical woody plants. USDA, Agricultural Research Service, ARPA Order No. 424(CR-13-67)(1967).

Figure VIII-1 - Picloram Residue at Various Depths in Three Forest Areas of Puerto Rico 12 Months after Application

At Victoria, the concentration of picloram at 6 inches did not exceed that of the surface till the 12th week and a detectable amount remained on the surface after 26 weeks at the 8 lb. per acre level. There were 8.8 inches of rain within 26 weeks after treatment at the Victoria site and 15.9 inches of rain during the same period at the College Station site. No detectable residue* was present after one year at either locations at any rate or depth.

In summary, the research conducted in Texas and Puerto Rico indicated that picloram leached through the soil profile rapidly in sand, but more slowly in heavy clay soil. Picloram will remain in soil for relatively long periods of time. These data and others indicate that disappearance from surface soils depends on the soil type and amount of rainfall. If one applies picloram at higher rates to clay soils in low rainfall areas, phytotoxic quantities will persist for a long period of time.

Cacodylic Acid (dimethylarsenic acid) and Methanearsonic Acid

Ehman (1965) reported that cacodylic acid has an extremely low vapor pressure and its translation in the soil is very slow. DSMA equivalent to 28 lb. per acre was applied to the top of soil column and leached with 60 inches of water, less than 10% of the applied compound came through a 12-inch column of sand. Another experiment performed with 15 lb. per acre of cacodylic acid in the same experimental setup and using an extrapolation of 60 inches of leaching water, gave a leaching rate of 9% for sand and 6% for sandy loam.

Other Herbicides

Diquat and paraquat are very persistent to leaching in soil column tests. Eighty-five to 95% of diquat and paraquat remains in the top 0.5 inch of the column (Coats et al., 1966).

Diuron leaching in Hawaiian sugar cane soils have been studied by Hilton and Yuen (1966). Diuron applied at the rate of 20 lb. per acre leached downward in sugar cane top soil about 2 inches when 16 increments of one acre inch of water were applied.

Generally, chemicals that are persistent are normally those that resist leaching and are retained in the surface layers of the soil. Ureas, substituted ureas, triazines, and 2,6-dichlorobenzonitrile are included.

The mobility of monuron is influenced directly by the amount of water applied and inversely by the time lapse between leaching (Danielson, 1956; Upchurch and Pierce, 1957; Burnside et al., 1963b). Sherburne et al. (1956) stated that the leaching of monuron depends on soil type and the amount of

* Determined by the normal growth of black valentine beans, planted in the soil not used for chromatographic analysis.

water applied. Erickson (1965) studied a range of monuron applications over a three-year period in relation to leaching in soil (Palouse silt loam). A bioassay of flax, peas and wheat was used. A summary of his results are as follows:

Year	Rainfall (inches)	Application Rate (lb. per acre)	Penetration (inches)
1	19.8	5	< 4
		10-20	10
		40	18
		80	24
		160	32
3	62.1	5	6
		10	10
		20	18
		40	24
		80-160	> 32

Day et al. (1961) made a survey of amitrole adsorption and decomposition in 55 soils gathered from the principal citrus areas in California. Leaching studies were made on the following soil types.

Chino silt loam - alluvial soil from the valley floor

Hanford sandy loams - light-textured soil from recent granitic alluvial deposits

Vista sandy loam - light-textured, upland soil, residual from granite.

The leaching of amitrole was determined by applying the herbicides to the surface of soil columns. Fifty milligrams of amitrole in 1 ml of water was added to the soil surface and leached into the soil with two successive 5-ml additions of water. Water was then continuously added at such a rate to maintain a 5- to 10-mm head of water above the soil surface.

The leachings were collected in 10-ml units for analysis. The amitrole moved readily with leaching water with wide variability among the soils. The leaching was directly related to the adsorptive capacity for amitrole of the soils as determined in another part of the study. The average total recovery of the herbicide in the leaching water for four replications of 50 mg of added amitrole was Hanford,54.6 mg (noted by the investigator as an obvious error), Vista, 46.5 mg, and Chino,46.0 mg. It is evident that leaching removes amitrole from the surface layer of the soil.

Photodecomposition

In arid regions with intense exposure to sunlight for many days out of the year, degradation of herbicides by light may be a major factor.

Chlorophenoxy Acid

Payne and Fults (1947) studied the effects of ultraviolet light on 2,4-D, the sodium, ammonium and triethylamine salts and methyl, ethyl and butyl esters, plus 2-methyl-4-chlorophenoxyacetic acid.

Hansen and Buckholtz (1952) and Bell (1956) determined that a breakdown product of the action of light on 2,4-D was 2,4-dichlorophenol. Very little research has been done on the chemical and biological factors that contribute to the fate of 2,4-D in surface waters and bottom muds. Aly and Faust (1964) examined the adsorption of a sodium salt of 2,4-D dichlorophenoxyacetic acid, 2,4-D isopropyl esters (47% of the ester), 2,4-D butyl ester (39% of the ester), 2,4-D isooctyl ester (69% of the ester), on clay minerals, biological degradation and the effects of ultraviolet irradiation. They used a mercury discharge lamp 660 w with a 30-cm tube as an ultraviolet source. Samples were placed in the double wall quartz jacket (90 ml capacity and a 4 cm depth) surrounding the lamp. Irradiation of the solutions of the sodium salt, the isopropyl and butyl esters of 2,4-D in distilled water produced 2,4-dichlorophenol within 20 min as shown in Table VIII-2. Concentrations of the 2,4-D compounds decreased continuously during the irradiation period. The ultraviolet irradiation of the sodium salts, the isopropyl and the butyl esters of 2,4-D for 100 min reached the amounts 67 to 83%.

Picloram (4-amino-3,5,6-trichloropicolinic acid)

Picloram is degraded rapidly by ultraviolet light. Tschirley (1967) studied the rates of decomposition of picloram exposed to sunlight, ultraviolet light and darkness. Other information on the effect of ultraviolet light on picloram in water has been reported earlier in the section on residues--water (p.224).

In these photodecomposition studies, 1 mg of picloram was spread evenly over the surface of an 8 cm petri dish or on soil placed within the petri dish. The source of ultraviolet light was a mineral light (model R-51 lamp) which provided approximately 155 μw of shortwave ultraviolet radiation per square centimeter. Picloram content was determined after 48 and 168 hr exposure to the light conditions. It was found that the picloram was deactivated more by ultraviolet light than by sunlight. By chromatographic analysis, 60% of 1 mg of picloram applied to petri dishes was degraded by ultraviolet

TABLE VIII-2

EFFECT OF ULTRAVIOLET IRRADIATION ON 2,4-D COMPOUNDS IN DISTILLED WATER

Time (min.)	Concentration (mg/liter)	% Remaining	2,4-DCP[a] (mg per liter)	pH
		2,4-D Sodium Salt		
0	70.0[b]	--	0.0	7.0
20	59.2	84.5	9.0	4.0
40	47.6	68.0	9.0	4.0
80	27.3	39.0	4.2	3.3
100	21.0	30.0	3.8	3.0
		2,4-D Isopropyl Ester		
0	90.0[b]	--	0.0	7.0
20	65.0	72.2	10.0	5.3
40	43.0	47.8	10.0	4.2
80	20.0	22.2	6.2	3.0
100	15.0	16.7	5.6	3.0
		2,4-D Butyl Ester		
0	70.0[b]	--	0.0	7.0
20	53.0	75.7	4.0	--
40	40.0	57.1	5.4	--
80	27.0	38.6	5.6	3.6
100	23.0	32.6	3.0	3.0
		2,4-Dichlorophenol		
0	36.0	--	--	7.0
10	24.0	94.4	--	--
20	27.0	75.0	--	5.3
40	17.0	47.2	--	4.3
80	4.4	12.2	--	3.5

a/ 2,4-Dichlorophenol.
b/ Expressed as the acid equivalent.

light after 48 hr, whereas 35% was degraded by sunlight. After seven days' exposure, more than 90% was degraded by ultraviolet light and 65% for sunlight. In soil, only 15% of the picloram was degraded by exposure for seven days to sunlight.

Cacodylic Acid (dimethylarsenic acid; methanearsonic acid)

No information was found in the literature in reference to the photodecomposition of cacodylic acid.

Other Herbicides

The effect of ultraviolet light has been studied on a number of herbicides (substituted ureas, triazines, bipyridyl compounds, uracils, etc.). Atrazine and simazine (Jordan et al., 1964a, 1965) and ametryne (Jordan et al., 1964a) will undergo photodecomposition and there are differences in the changes in the absorption spectra for these herbicides when exposed to sunlight and ultraviolet light.

Monuron and diuron are sensitive to photodecomposition. Irradiation for 28 hr with an 85-w mercury vapor ultraviolet lamp resulted in a 75% decrease in biological activity, and diuron appeared to break down more rapidly than monuron (Weldon and Timmons, 1961). Jordan et al. (1964b) reported that monuron, diuron, neburon and fenuron were all degraded by light. They irradiated the herbicides with ultraviolet light (253.7 mμ) and sunshine. Exposures ranged up to 1,080 min. They obtained different spectral changes with irradiation from sunlight and shortwave ultraviolet light which indicated degradation of the original compounds and the formation of new compounds.

A number of herbicides that undergo photodecomposition have been studied from the standpoint of the effect of far, middle and near ultraviolet (Jordan et al., 1965). The experiment included four substitutes, monuron, diuron, neburon, fenuron; two triazines, simazine and atrazine; and two uracil herbicides, bromacil and isocil. For monuron, neburon and fenuron, the most rapid loss occurred during the first 24 hr. A steady-state situation was reached with no further herbicide loss for these three chemicals. In comparing simazine and atrazine, the latter degraded most rapidly during the first 80 hr and continued to disappear at a slower rate. For bromacil and isocil, the loss was almost the same for the two compounds when irradiated with middle and far ultraviolet. More bromacil than isocil was lost under near ultraviolet.

Paraquat and diquat are drastically affected by ultraviolet radiation (Funderburk et al., 1966) and (Coats et al., 1966). Coats found that the greatest decomposition takes place in the first 24 hr. Over 60% of the paraquat and over 30% of the diquat is decomposed. After three days, 75% and 50%

of the herbicides were destroyed, respectively. Funderburk et al. (1966) evaluated the effect of ultraviolet light on diquat and paraquat in the absorbed state. A sandy loam soil (66% sand, 14% silt and 20% clay, 0.25% organic matter) kaolinite and montmorillonite were added individually to solutions of C^{14} labelled diquat and paraquat and placed under ultraviolet light source (240-260 millimicron range). The loss of radioactivity was drastically reduced as compared to the herbicides when exposed without an absorbent.

IX. ECOLOGICAL CONSEQUENCES OF HERBICIDE USE

A. Concept of the Ecosystem

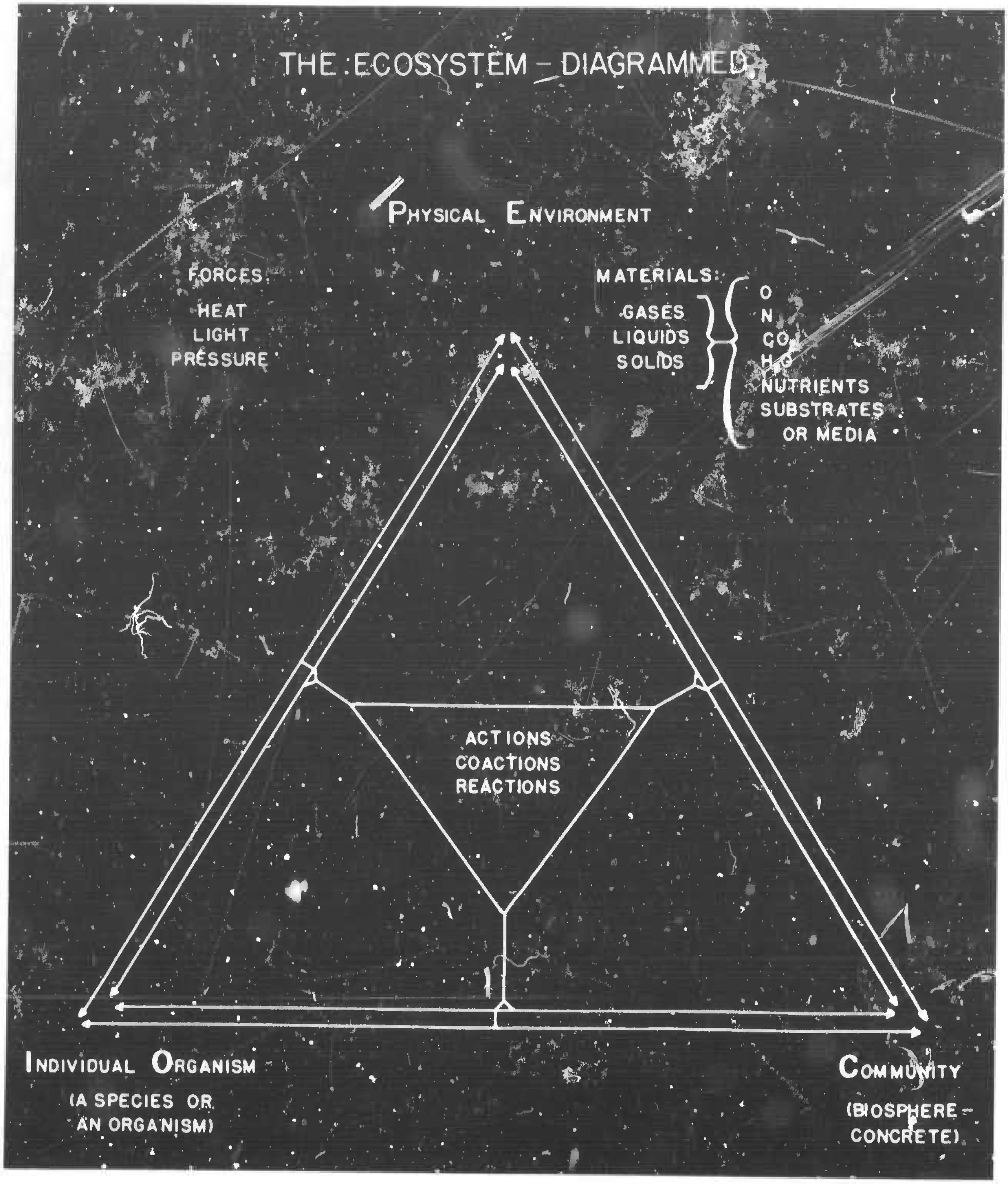
Civilized man is constantly changing his environment to make it more suitable for his immediate needs. These changes are accomplished in various ways: cutting, plowing, burning, grading, flooding, and most recently by the spraying of various chemicals. Prior to those "induced" environmental changes, the primitive human activities of gathering, hunting and herding had already interfered with the "natural" landscape, and disturbed the environment (Dansereau, 1957). The biological effects of this manipulation of the environment have recently become a matter of deep concern. Our knowledge of all the various aspects of the problem is so woefully lacking, however, as to make impossible an accurate analysis.

The term ecosystem was first used by Tansley (1935) to denote the interaction between the living organisms within the community and the physical factors of the environment, see Figure IX-1.

An ecosystem involves the capture and accumulation of energy and matter and their circulation, and transformation through the medium of living things and their activities. Photosynthesis, herbivory, predation, decomposition, parasitism, and symbiotic activities are among the principal biological processes responsible for the transport and storage of materials and energy, and the interactions of the organisms engaged in these activities provide the pathways of distribution (Evans, 1956). The food chain is an example of such a pathway.

In the abiotic (nonliving) part of the ecosystem, circulation of energy and matter is completed by such physical processes as evaporation and precipitation, erosion and deposition. The ecologist, then, is primarily concerned with the quantities of matter and energy that pass through a given ecosystem and with the rates at which they do so. Of almost equal importance, however, are the kinds of organisms that are present in any particular ecosystem and the roles that they occupy in its structure and organization. Cain (1966) illustrated the complex of relationships of ecological action in a terrestrial ecosystem (Figure IX-2). Thus, both quantitative and qualitative aspects need to be considered in the description and comparison of ecosystems.

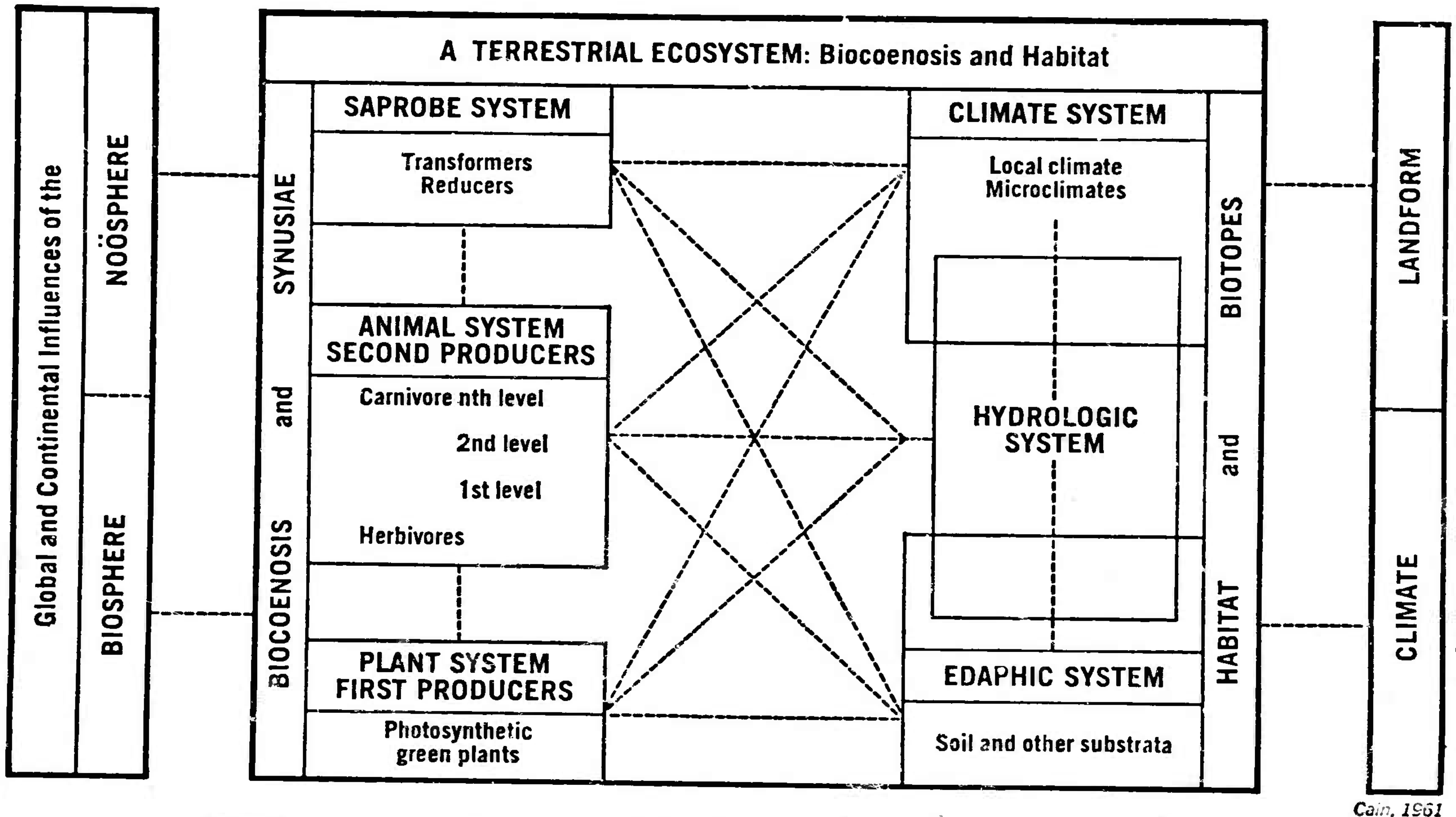
Ecosystems have a complex of regulatory mechanisms, which, in limiting the numbers of organisms present and in influencing their physiology and behavior, control the quantities and rates of movement of both matter and energy. Processes of growth and reproduction, agencies of mortality (physical as well as biological), patterns of immigration and emigration, and habits of adaptive significance are among the more important groups of regulatory mechanisms.



Courtesy P. C. Lemon and Burgess Publishing Company

Figure IX-1 - The Ecosystem-Diagrammed

Source: Lemon, P. C., Field and Laboratory Guide for Ecology, Frontpiece, Burgess Publishing Co., Minneapolis (1962)



Legend: --------- Relations of the Ecological Action System

Courtesy S. A. Cain (1966) and the Natural History Press

Figure IX-2 - Relations of the Ecological Action System

Ecosystems in the environmental relationships occur organizationally between the community and the bioclimates. The extremes of organization on the environment are represented by the molecule and the biota.

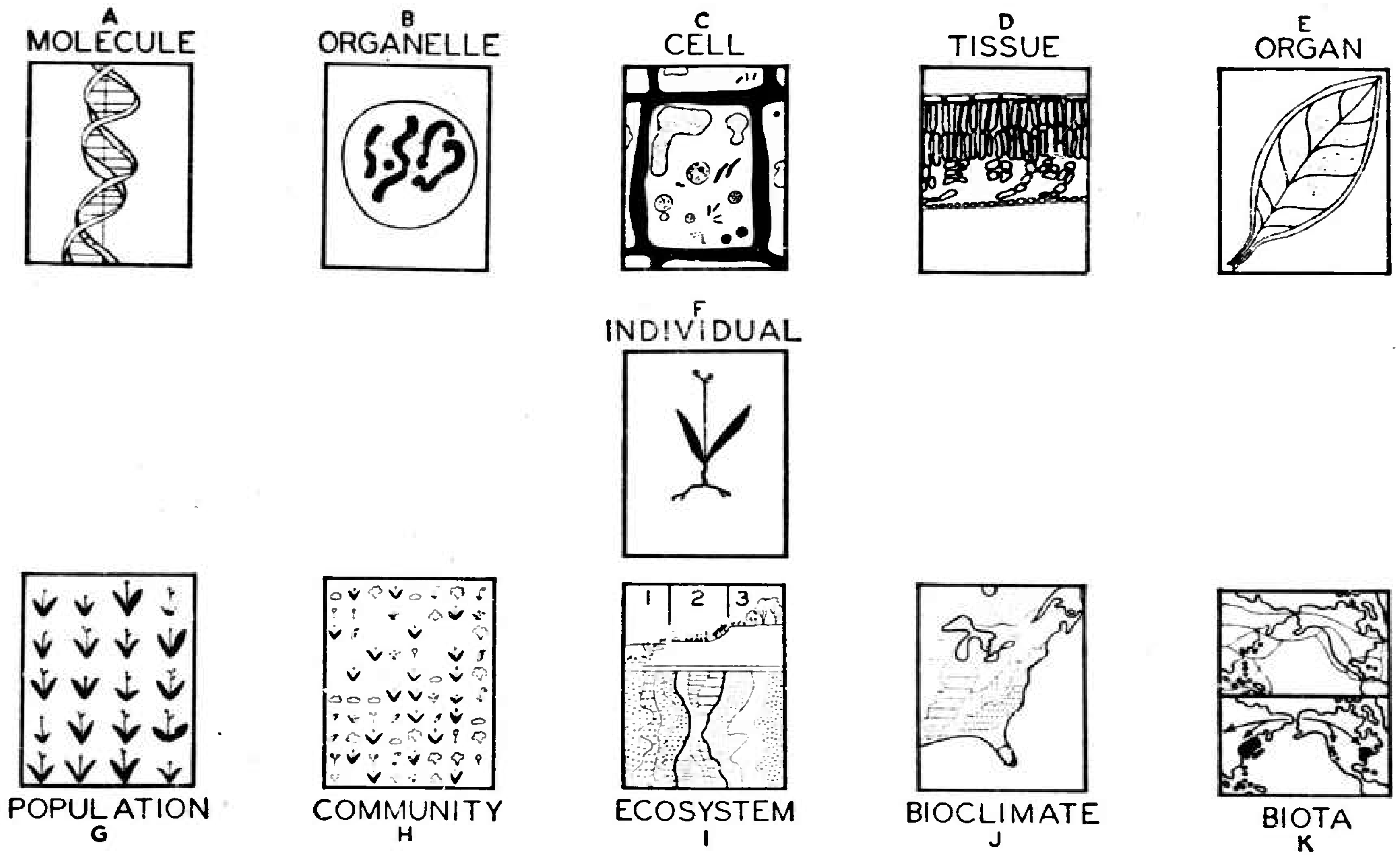
The assemblage of plants and animals in an ecosystem usually consists of numerous species, each represented by a population of individual organisms. However, each population can be regarded as an entity in its own right, interacting with its environment (which may include other organisms as well as physical features of the habitat) to form a lower level of organization that likewise involves the distribution of matter and energy. In turn, each individual animal or plant, together with its particular microenvironment, constitutes a still lower level of organization.

Reference to Dansereau's "Scheme of the Biosphere" (Figure IX-3) indicates the ecological components, mentioned herein, which are involved at various levels of environmental relationship to the individual species.

All ranks of ecosystems are open systems, not closed ones. Energy and matter continually escape from them in the course of the processes of life, and they must be replaced if the system is to continue to function. The pathways of loss and replacement of matter and energy frequently connect one ecosystem with another, and therefore it is often difficult to determine the limits of a given ecosystem. At whatever level we may wish to consider it, the ecosystem stands as a basic unit of ecology.

The whole complex of the plants and animals forming a community, together with all the interacting physical factors of the environment, form a single unit. This takes into account <u>all</u> the living creatures in the community, from the fungi, bacteria and nematode worms living in the soil to the mosses, caterpillars and birds in the trees; and all the factors of the environment, from the composition of the soil atmosphere and soil solution to wind, length of day, relative humidity, atmospheric pollution, etc. All do have some effect on the balance of the whole. The final aim of ecology--the complete understanding of ecosystems--is an ideal one can scarcely hope to attain. It is nevertheless an ideal well worth pursuing, and valuable progress has been made toward it. The first stage is to simplify the problem by studying different aspects of the ecosystem independently (Ashby, 1965).

A forest, a lake, a savannah, a marsh, a desert, and a prairie are all examples of ecosystems at the community level. Although each may have a different composition of environmental and biological factors, the basic structure, along which matter and energy transfers are made, is very similar.



Courtesy Natural History Press (Dansereau, 1966)

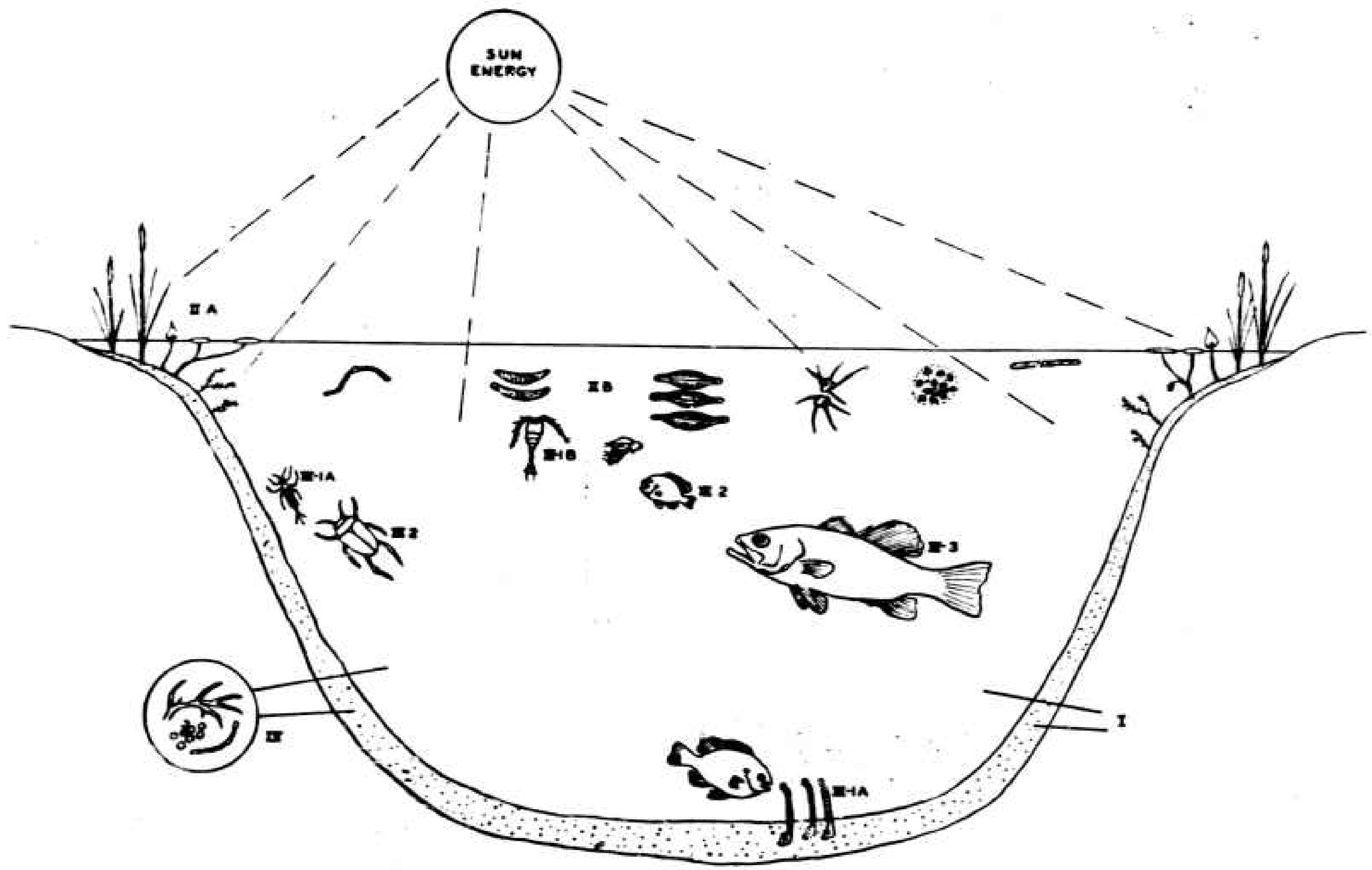
Figure IX -3 - A Scheme of the Biosphere, Showing the Orders of Magnitude of the Environmental Relationship. Eleven levels are illustrated; from upper left to right, below the level of the individual; from lower left to right, above the level of the individual.

All function, and indeed all life, within an ecosystem depends upon the utilization of an external source of energy, solar radiation. A portion of this incident energy is transformed by the process of photosynthesis into chemical energy in the structure of living organisms. In the language of community economics, autotrophic plants are producer organisms, employing the energy obtained by photosynthesis to synthesize complex organic substances from simple inorganic substances. Although plants again release a portion of this potential energy in catabolic processes, a great surplus of organic substance is accumulated. Animals and heterotrophic plants, as consumer organisms, feed upon this surplus of potential energy, oxidizing a considerable portion of the consumed substance to release kinetic energy for metabolism but transforming the remainder into the complex chemical substances of their own bodies. Following death, every organism is a potential source of energy for saprophagous organisms (feeding directly on dead tissues), which again may act as energy sources for successive categories of consumers. Heterotrophic bacteria and fungi, representing the most important saprophagous consumption of energy, may be conveniently differentiated from animal consumers as specialized decomposers of organic substance. Waksman has suggested that certain of these bacteria be further differentiated as transformers of organic and inorganic compounds. The combined action of animal consumers and bacterial decomposers dissipates the potential energy contained in organic substances, while transforming them to the inorganic state (Lindeman, 1942). A diagrammatic protrayal of the "pond" ecosystem, as illustrated in Figure IX-4, defines the roles played by the functional individuals of this community as producers, consumers, and decomposers.

B. Food Chains

In the food chain concept, individuals of species S_1 are eaten by those of S_2, of S_2 by S_3, and S_3 by S_4, etc. In such a food chain S_1 will ordinarily be some autotrophic organism or material derived from such organisms (Hutchinson, 1959).

Forbes (1887) said, "If one wishes to become acquainted with the black bass, for example, he will learn but little if he limits himself to that species. He must evidently study also the species upon which it depends for its existence, and the various conditions upon which these depend. He must likewise study the species with which it comes in competition, and the entire system of conditions affecting their prosperity; and by the time he has studied all these sufficiently he will find that he has run through the whole complicated mechanism of the aquatic life of the locality, both animal and vegetable, of which his species forms but a single element."



Courtesy W. B. Saunders Company

Figure IX-4 - Diagram of the Pond Ecosystem

Basic units are as follows: I, abiotic substances-basic inorganic and organic compounds; IIA, producers-rooted vegetation; IIB, producers-phytoplankton; III-1A, primary consumers (herbivores)-bottom forms; III-1B, primary consumers (herbivores)-zooplankton; III-2, secondary consumers (carnivores); III-3, tertiary consumers (secondary carnivores); IV, decomposers-bacteria and fungi of decay.

Source: Odum, E.P., (Fig. 3, p. 14), Fundamentals of Ecology, 2nd ed., W.B. Saunders Co., Philadelphia (1959)

Through a series of studies at Silver Springs, Florida, H. T. Odum (1957) calculated productivity figures for each link in the food chain (see Figure IX-5). The total standing crop of primary producers averaged 26 oz/sq yard. At the next level were first-order consumers -- snails, turtles, mullet, and other plant-eating fish, and a variety of aquatic insects. These herbivores averaged 1.2 oz/sq yard. Second order consumers, such as sunfish, catfish, predatory beetles and other small carnivores, came to 0.35 oz. Third-order consumers, primarily largemouth black bass and gar, averaged only 0.05 oz/sq yard.

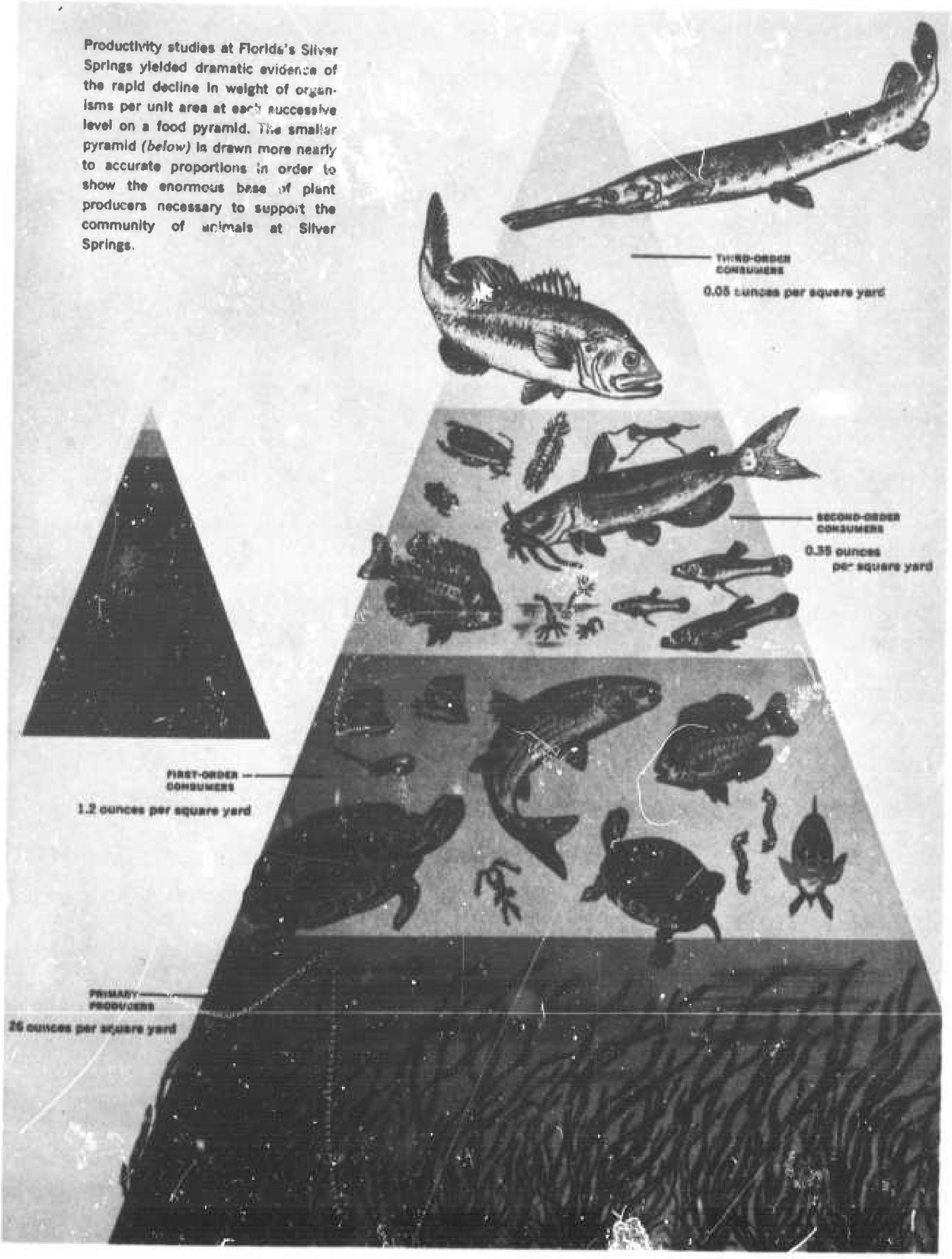
Although nature seldom, if ever, builds ecosystems with simple and quantitatively equivalent pyramidical structures, ecologists generally agree that ecosystem food chains transmit approximately 10% of the energy entering one level to the next level above it. The concentration of foreign chemical entities by biological amplification via ecosystem food chain dynamics has become a concern. For example, Woodwell (1967) found that the insecticide (DDT) was concentrated in the Long Island estuary ecosystem. He found residues of DDT and its derivatives in plankton, herbivorous fish, carnivorous fish, and fish-eating birds of 0.04, 1.00, 2.07 and 75.5 ppm, respectively. Other studies have been reported in the concentration of Ce^{137} in a food chain sequence. To our knowledge there have been no reports of sequential biological buildup of organic herbicides.

C. Definition of Specific Ecosystems

In an attempt to come to some understanding as to assess the use of herbicides upon an ecosystem, we are confronted with serious knowledge deficiencies. A specific "natural" ecosystem has not yet been completely defined in that man has not been able to analyze one in its entirety. Figure IX-6, the terrestrialforest ecosystem, and Figure IX-7, the desert ecosystem, illustrates some of the complexities involved in such an undertaking.

The difficulty of performing a complete analysis of a baseline ecosystem is enormous. The complex food chain of the weed, "ragwort" (Figure IX-8) is probably the most comprehensive food chain study ever done (Harper, 1957). The figure illustrates the complex inter-relations from "plant growth requirements" to "hyperparasites." Harper reported that many links are still missing.

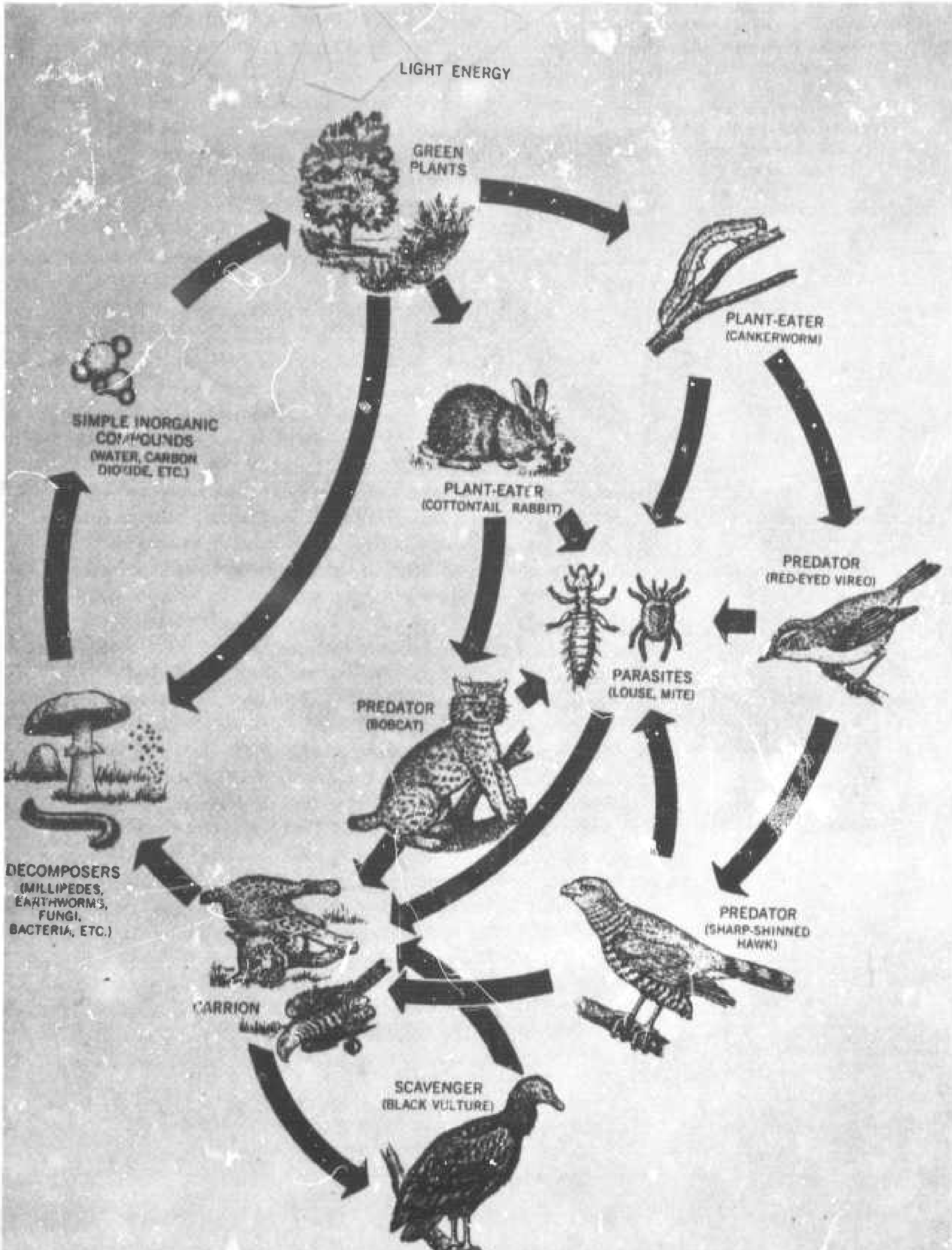
Probably the greatest man-generated ecological disturbance has been the plow, followed by the axe and uncontrolled burning. The ecological changes wrought by herbicides at their current rate of use has not by any measure reached the proportion of ecological disturbance as the other elements mentioned above.



Courtesy McGraw-Hill and World Book Encyclopedia

Figure IX-5 - Fish Pond Ecosystem Productivity (Food Chain)

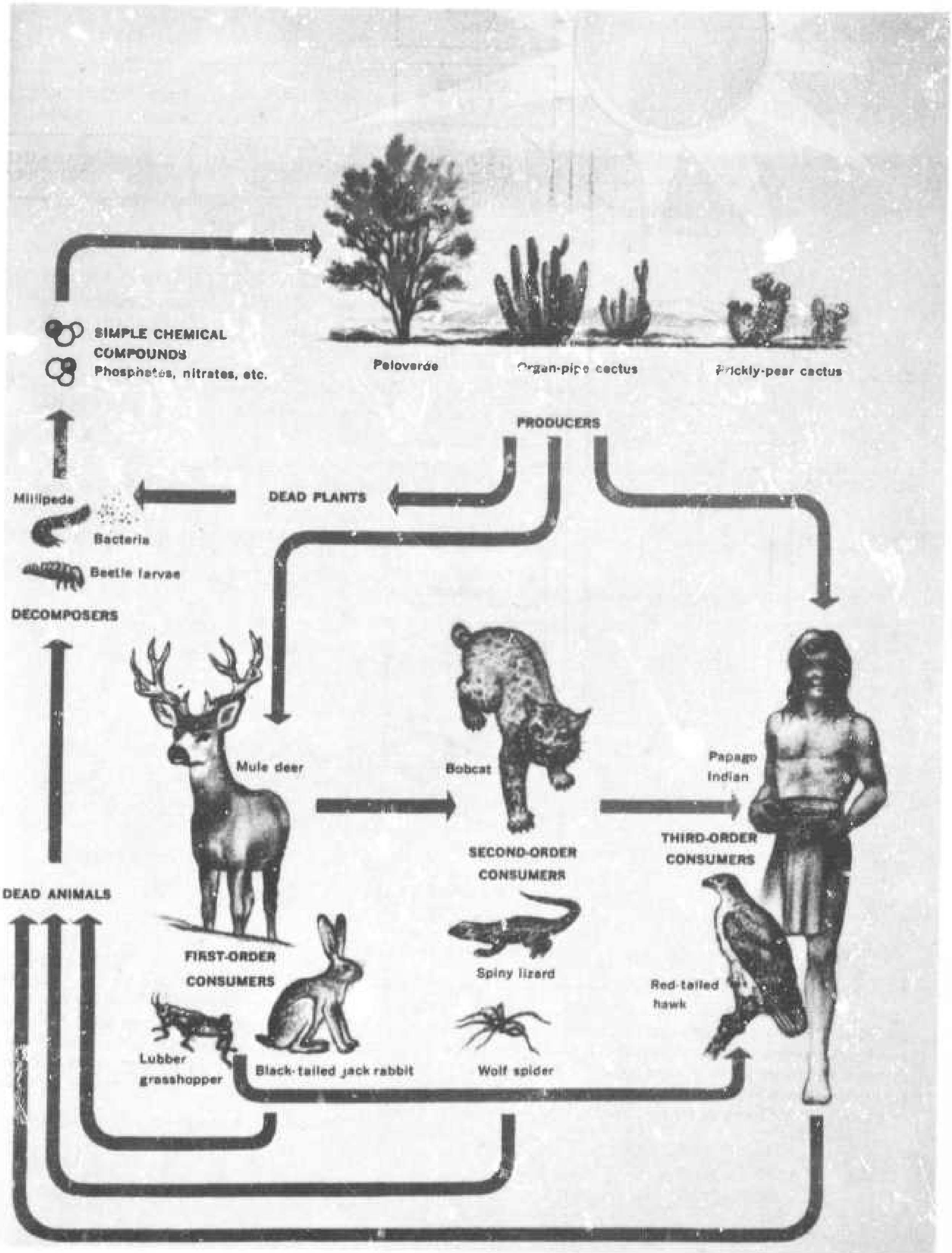
Source: Usinger, R. L. (ed.) The Life of Rivers and Streams, p. 125, McGraw-Hill Book Company, New York (1967)



Courtesy McGraw-Hill and World Book Encyclopedia

Figure IX-6 - Terrestrial Forest Ecosystem

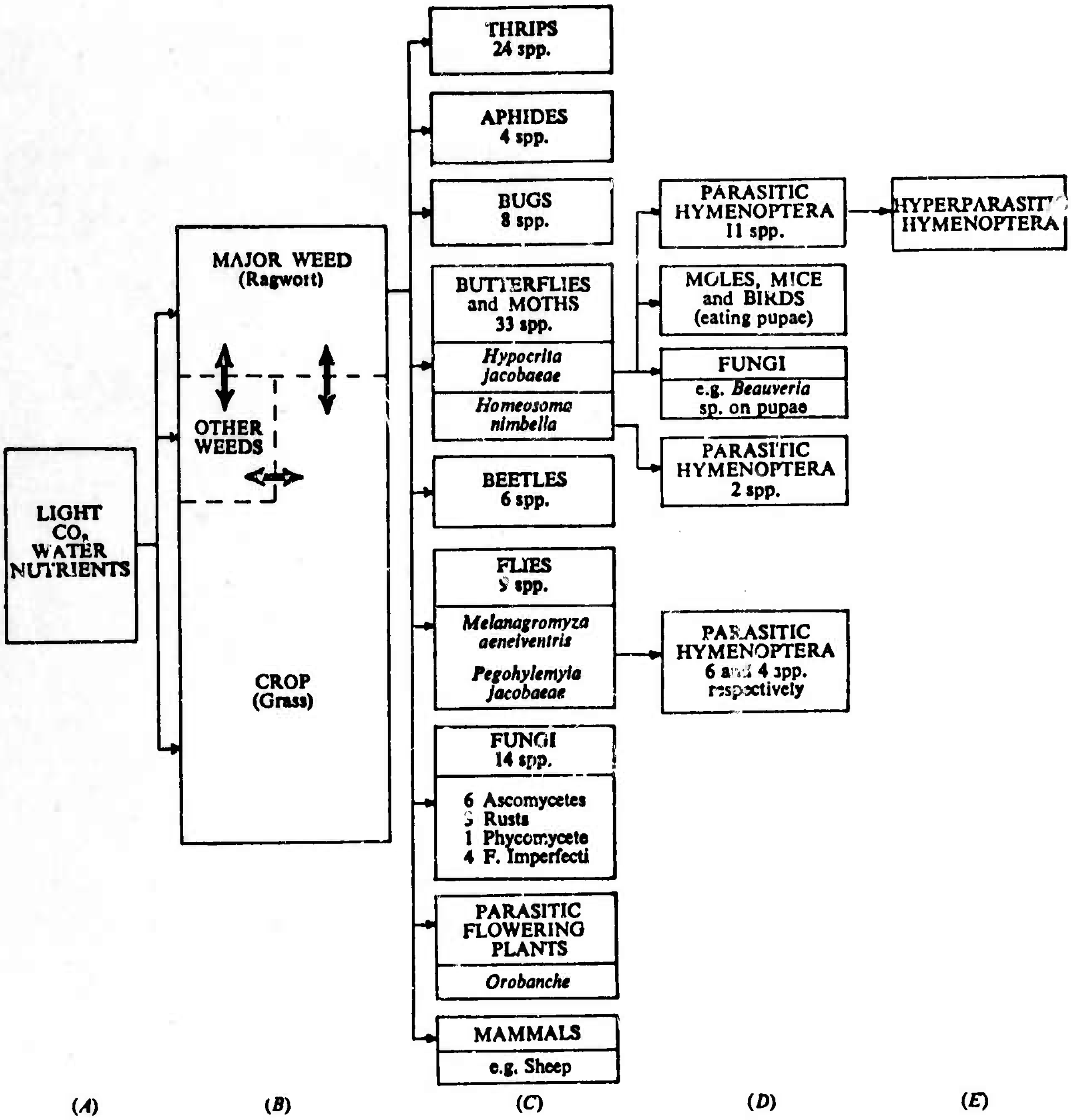
Source: McCormick, J., (ed.) The Life of the Forest, p. 25, McGraw-Hill Book Company, New York (1966)



Courtesy McGraw-Hill and World Book Encyclopedia

Figure IX-7 - Terrestrial Desert Ecosystem

Source: Sutton, A., and M. Sutton (eds.) The Life of the Desert, p. 55, McGraw-Hill Book Company, New York, 1966



Diagrammatic food chain of a weed exemplified by ragwort, *Senecio jacobaea*. The columns denote: (*A*) plant growth requirements; (*B*) weed-crop relationships; (*C*) organisms attacking ragwort; (*D*) parasites and predators; and (*E*) their hyper-parasites. The numbers of species are those so far recorded in the U.K., but the list is far from complete, particularly for parasites and hyper-parasites. The arrows in (*B*) indicate the changes in composition of a weedy crop (ragwort-infested pasture, in this instance) which may follow changes induced in the food chain: expansion or contraction of the ragwort population is relative to that of the crop or other weeds. Herbicidal treatment of ragwort may be followed by re-invasion of other weeds or expansion of the crop, or both, and all the organisms in the food chain are affected.

Figure IX-8

Source: Harper (1957)

A thorough study of the ecosystem should be made as nearly in its unaltered condition as is possible. This would involve population studies of <u>all</u> the species of plants and animals, regardless of how insignificant they might seem to be. Measurements of the total biomass and biotic potential would also need to be made. In spite of the logarithmic mode of current scientific advances, no reasonably comprehensive and balanced scheme of the quantitative ecology of a single "natural" ecosystem exists. Nor is one likely to be produced in the near future unless current support of such a study is significantly increased. The immensity of such an undertaking is clearly revealed in the sole attempt to approach the quantitative ecology of a dynamic woodland ecosystem. Ovington (1962) has described four processes* of the many depicted in Figure IX-9, which illustrates most of the dynamic processes in a forest ecosystem. Furthermore, he has reported that although his purpose was,"to stress the fundamental unity of ecosystem physiology, yet paradoxically, for convenience of description, the four processes described (and extremely well so) have had to be considered separately." He found it difficult if not impossible with the means at hand to describe the many interrelationships which exist in a natural woodland ecosystem as well as their numerous and diverse interconnections.

The quantitative determination of the biotic potential of any ecosystem, appears to be beyond our current scientific capability, since the biomass, though measurable,is not a completely satisfactory estimation of net primary productivity. In addition, Ovington stated, "it is impossible to generalize on long term trends in the nutrient budget." This status of the nutritional "balance" persists,because the many diverse processes involved in chemical element circulation are interdependent functions of: (1) the character of the woodland ecosystem, (2) the particular chemical nutrient concerned and (3) the influence of man. The magnitude of ecological assessment in respect to the Vietnam bioclimate becomes evident when one considers the proportionality of the SVN** vegetational biomass of 600,000 lb/hectare to the England/U.S.A. average woodland plant biomass of a few thousand lb/hectare.

However, progress toward the development and understanding of baseline ecosystem economics is being made to some degree, despite the lack of precise means of delineating specific ecosystems. The task of synthesizing fragmentary and incomplete knowledge, gained by different disciplines, probably represents the most challenging and rewarding problem facing socially responsible scientists today. The ecosystem approach serves not only as a basis for evaluating and collating the existing, diverse data but also acts as a

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* Organic matter dynamics, energy dynamics, the hydrolgic cycle, and circulation of chemical elements.

** South Vietnam.

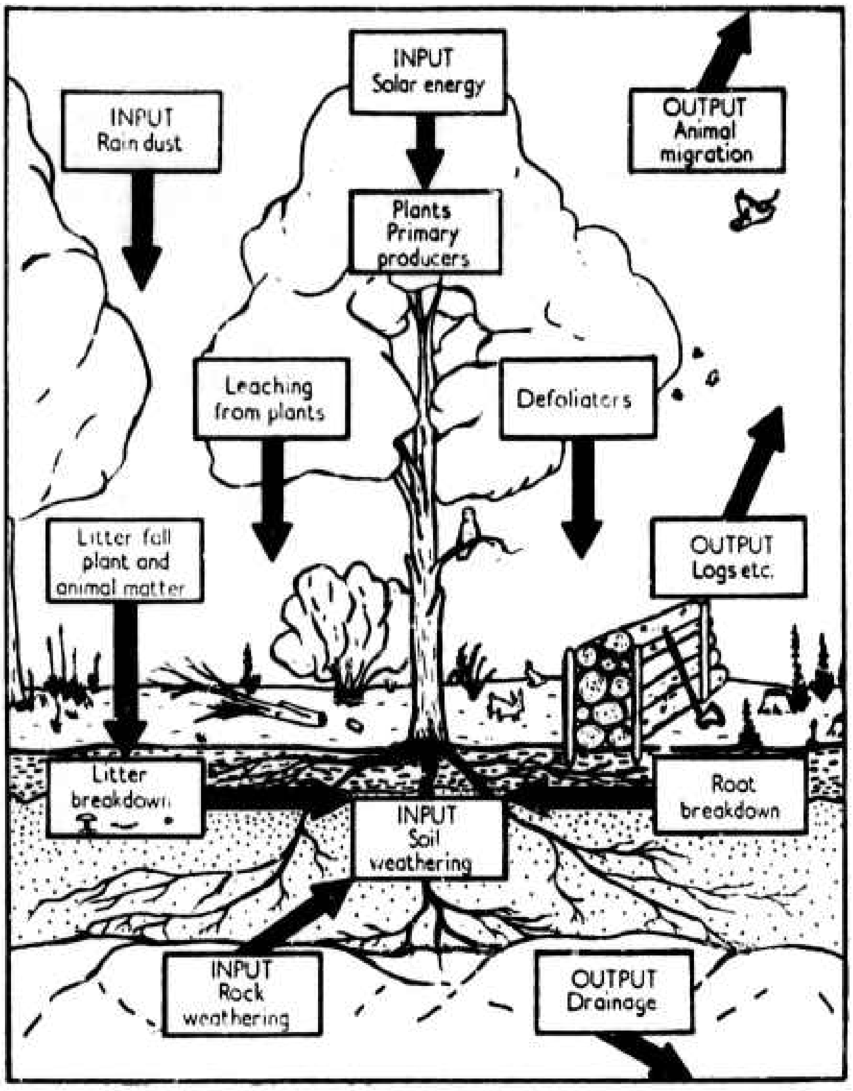


Figure IX-9 - Forest Ecosystem Dynamics

Source: Ovington, J. D., "Quantitative Ecology and the Woodland Ecosystem Concept," Adv. Ecol. Res., 1, 106 (1962) guide for future research support by highlighting omissions, revealing potentially undesirable ecological aspects, and suggesting the most fruitful areas for intensive study.

After the application of the herbicide many questions will have to be answered repeatedly over a long period of time: What plants in the ecosystem were destroyed? What percentage of the total energy potential is thus eliminated? What animals, including insects, are eliminated or seriously impaired by the loss of their food plants? What plants move in to replace those lost? What is the total change in the biotic potential? Is it increased or decreased? What animals replace those lost or driven out? What predatory changes occur? Certainly many more questions would arise as these are answered.

D. Effects Of Herbicides On An Ecosystem

Ecological Effects on the Biotic Factors (Flora and Fauna)

Many thousands of different kinds of plants cover practically every available space on the surface of the earth. These plants, from the simplest unicellular algae to the largest Sequoia, are able to take water and carbon dioxide, utilize the radiant energy from the sun and in the presence of chlorophyll, convert them into simple sugars. Some of the simple sugars are compounded into starches, celluloses and other carbohydrates. Others are changed into proteins, fats and oils, various pigments, resins, gums, pectins and other substances by the addition of minerals (from the water medium or from the soil) and the utilization of the energy tied into the total process by photosynthesis. Loomis (1951) estimated that the plants of all the world's oceans fix 15.5×10^{10} tons of carbon per year; whereas land plants fix only 1.9×10^{10} tons of carbon per year into complex food compounds.

One of the generalities widely accepted in ecology is that no two closely related species can occupy the same niche. One of them is better able to take its requirements from a particular environment than the other. If, however, they are found growing and thriving very closely together, then their requirements are sufficiently different, such that adverse competition does not occur. Instead the relationship may be one of commensalism, mutualism or neutralism. Some plants are able to grow and thrive in a wide variety of habitats while others are restricted to very narrow niches in the biosphere. Basically, however, the vegetation is a direct result of the environment in which it grows. It is controlled by such abiotic factors as moisture, temperature, intensity and quality of light, humidity, soil, soil minerals, altitude, and wind; and such biotic factors as other plants, animals, parasites, etc.

In the normal course of events plants die either because they have completed their life cycle, or they have been unable to compete successfully with other plants, or are destroyed by disease, by fire or frost, or have been eaten by animals. Fortunately, the space which they occupied is then taken over by some other plant; whether that space is small or large, whether it requires one plant or many, it (the ecological niche) soon becomes filled.

New islands are often formed by volcanoes such as Krakatau (Richards, 1952 and Ingersoll, 1963) and Surtsey (Thorarinsson, 1967) or by coral reefs covered by sand, but it is not very long until flora and fauna invade and become established. The same can be said of fan-shaped deltas formed at the mouths of large rivers. Areas that have been burned over are soon covered with vegetation; often a very characteristic type of plants produce the first plant cover. Many other forces of nature such as glaciers, land-slides, winds floods and earthquakes make great barren areas that are, in the course of time, invaded by an extensive population of plants.

Man is not restricted to a specific species of plant for his major food supply as many animals are, but the number of food plants which he can and does utilize is comparatively limited. In order to cultivate these in-sufficient quantities to meet his needs, vast areas of "natural" vegetation have been cleared, forests have been removed by axe, fire, and herbicides, and "natural" grasslands have been plowed. In many instances where these lands have been abandoned, they have, in a few years, returned to grasslands and forests.

In Southeast Asia, North and West Africa, and in the South American tropics an interesting type of agriculture has been employed called "rai." Great areas of jungle are cleared, usually by axe and fire; planted for three or four crop years and then permitted to go back to forest. There are some very logical reasons for this: (1) what mineral matter is present in the soil is rapidly leached away, if the plants are unable to utilize it as rapidly as it is released by chemical and/or humus decomposition; (2) the accelerated action of microbial decomposition of the humus at this high temperature and humidity occurs so rapidly that the soil is soon so lacking in minerals available for plant use that it cannot support a crop; and (3) the removal of humus changes the structure of the soil so drastically that cultivation is almost impossible. Each succeeding time that a particular area is cleared it requires a longer time for the original, "natural" ecosystem to be restored.

In North Africa, particularly, this has followed an interesting pattern. The abandoned fields, after several cycles of use and disuse, could no longer support forest growth and reverted <u>only</u> to brush land. The natives herded goats and sheep into this area to take advantage of the browse. Over-grazing eventually destroyed the shrubs, the bunch grasses soon disappeared, and the land became a desert. This process has been given the name "Saharization." In some of the areas of Vietnam the "rai" fields have now become brush or grasslands (Williams, 1965).

Other interesting ecological changes are occurring in various parts of the United States due to agricultural practices. The grasslands of the Great Plains were maintained by periodic firing by lightning. For a long period of time man thought that all fires in nature were bad and made every effort possible to control or eliminate fires. In Texas, much of the grassland has been lost due to the establishment of many "weedy" trees and shrubs, mesquite, winged elm, various species of cacti, cedar elm, lote bush, and many others. In the southeastern part of the United States the longleaf pine savannahs were fire maintained. By the control of these fires many acres of these pinelands are being transformed into useless scrub oak. (Lutz, 1963).

All fauna, which of necessity must rely either directly or indirectly upon the plants for their food, are seriously affected by the disturbance of their natural habitat and food plants. The degree of this effect is in direct proportion to the degree of disturbance. If 10% of the total food potential for a particular bird, animal, etc., is removed, the population of that species must be reduced by 10% in one way or another. If he moves into another area, the chances are that it too is supporting a maximum population and the competition there will eliminate an equal number.

Many of the fauna that are rare or in danger of extinction, are so because of the increasing influence of mankind as the dominant species. The destruction of habitat is the primary reason that most rare forms have become "endangered." In most cases in the past, when the causative agency was made aware of the consequences and a preserve established or protective measures taken, the "endangered" species survived. For our purpose here, a few of those species currently considered rare and in danger of extinction and the reasons for their decline are shown in Table IX-1.

There are a number of endangered species endemic to Southeast Asia. The Douc Langur (Pygathrix nemaeus) is a monkey which eats almost entirely leaves (Crandall, 1964). It takes no flesh. It has long been on the endangered list and it "is perhaps the most colorful of all mammals" (Sanderson, 1955). The crested or Indochinese gibbon (Hylobates concolor) is another endangered jungle species rarely ever seen on the ground. It feeds on fruits, buds, leaves, insects, and birds' eggs (Crandall, 1964).

The rare Kouprey (Bos sauveli), a cow that was not even discovered until 1936, is limited to 800 individuals or less in central Cambodia. Very little is known about this strange species and much of its habitat has already been eliminated through forest destruction (Ziswiler, 1967).

TABLE IX-1

ENDANGERED SPECIES OF THE WORLD

Species	Description	Reason
Kouprey a/	Mekong River	Military hunting
Black-footed Ferret	North America Interior Plains	Loss of host species (prairie dog)
Broad-nosed Gentle Lemur	Lake Alaotra	Loss of habitat (food)
Blue Whale	Antarctic to Tropic	Over exploitation
Douc Langur b/	Vietnam	Food, tree leaves only
Sumatron Rhinoceros	Vietnam/Burma	Hunting (Black Magic)
Indo-Chinese Gibbon	Indo-China	Tree dweller, feeds on foliage and insects
Thailand Brow-antlered Deer c/	Vietnam/Thailand	Severe hunting
Red Wolf	Texas	Trapping, hunting, habitat change
Western Giant Eland	Western Africa	Hunting and rinderpest
Javan Rhinoceros	Western Java	Agriculture and hunting
Wooly Spider Monkey	South East Brazil	Habitat loss (Agric)
Hipsid Hare	Pakastan	Habitat loss (Agric)
California Condor	Washington, California	Habitat, hunting and rodenticides
Everglade Kite	Florida	Habitat and food chain loss
Whooping Crane	Canada, Texas	Hunting and habitat loss
Ivory-billed Woodpecker	Texas	Logging of big swamp trees
Cebu Black Shama	Philippines	Deforestation
Grizzly Bear	Montana, Wyoming, Alaska	Poison and habitat loss
Southern Bald Eagle	Atlantic and Gulf Coast	Reduced reproduction due to food with pesticides
American Peregrine Falcon	Alaska to Argentina	Kill and reproduction reduced by cumulative pesticides
Attwater's Greater Prairie Chicken	Texas	The "plow"
Lesser Prairie Chicken	Kansas, Colorado, N. Mexico, Texas	Removal or reduction of woody vegetation
Yuma Clapper Rail	Colorado River	Marsh drainage and aquatic weed control
Golden-cheeked Warbler	Texas	Brush eradication
Dusky Seaside Sparrow	Cape Kennedy	Alter habitat for mosquito control
San Francisco Garter Snake	San Francisco	Habitat destruction by housing and weed control
Pine Barrens Tree Frog	New Jersey	Jet airport
Shortnose Sturgeon	Hudson River	Pollution
Arctic Grayling	Northwest United States	Loss of habitat due to logging and irrigation
Lahontan Cut-throat Trout	Nevada, California	Forest removal
Little Colorado Spinedace	Little Colorado River Tributaries	Pollution and chemical rehabilitation of habitat
Niangua Darter	Osage River Drainage	Lake of the Ozarks Construction, habitat sprayed

a/ Other Bovinae in Southeast Asia considered to be "rare" are the Gaur and the Banteng.
b/ On the current Red Data list of "Rare Endangered Mammals," but the information gap existing prevents the IUCN from reporting an accurate assessment of this animal's status.
c/ "On the verge of being lost," and the accurate status is inadequately known. A survey is required to produce data for its assessment. Kantrol (Personal Communication, in litt., to IUCN, June 20, 1964) has advised the IUCN to invite the Governments of South Vietnam and Laos to establish reserves on their borders with the previously established Cambodian reserves in Phom-Priech, in the Kratie province, in Koulen Promtep in the Siemreap/Kompong Thom region and in the Cardamons province. These proposed protective measures would allow undisturbed movement of the animals across the common frontiers.

Sources:
1. IUCN* - Red Data Book, I (Mammalia), Simon, N., (ed.), 1966, and Jan. '67 supplement, 1110 Morges, Switzerland.
2. Ibid., II (Aves), Vincent, J.
3. Rare and Endangered Fish and Wildlife of the United States, Resource Publication, 34, Committee on Rare and Endangered Wildlife Species, Bu. SF&WL, USDI, July 1966.
4. Office of Endangered Species, Fish and Wildlife Service, Bu. SF&WL, USDI, (a) Conservation Note No. 21, "Ivory-Billed Woodpecker," (b) Release No. 97173-67, "Ivory-Billed Woodpecker Found in Texas," Saults 343 5634, August 27, 1967, and (c) Release No. 97313-67 (Featured Material, Endangered Wildlife Series No. 4), "The Ivory-Billed Woodpecker," September 3, 1967.
5. Jenkins, J. H., personal communication to K. W. Dockter on November 20, 1967.
6. IUCN - International Technical Conference on the Protection of Nature, Proced.and Papers, UNESCO, Lake Succes (1949).

* International Union for the Conservation of Nature and Natural Resources.

Jenkins (1967) has suggested that defoliation in Vietnam/Cambodia may actually assist in increasing the numbers of Kouprey through increased browse production from developing bamboo and other grasses in the defoliated areas. Worldwide interest has developed in the Kouprey, because it is considered to be one of the most primitive of living taurines and a surviving remnant of a mid-Miocene form, ancestral to both the wild and domestic cattle of modern times. Because of this an inspired effort was made on two different occasions to evaluate the status of the Kouprey both ecologically and biologically. Wharton (1966) mentioned both of these expeditions, which he personally had the privilege to participate in, but indicated that both research efforts were abruptly terminated as a result of, first in 1952, the handicap imposed by "Viet Minh operations," and in 1964, "hindrances caused by political difficulties." Thus, the main objective, the status of the Kouprey's ecology remains unknown.

The Gaur (Bos gaurus) is another rare bovine, and one subspecies, the Malayan, is down to 300 individuals. The Banteng is a reddish forest cow of restricted range in Southeast Aisa.

Wildlife populations are in direct proportion to food, cover, water, and special factors. In fact, all scientific wildlife management is based on this premise (Martin, et al., 1951; DeVaney, 1967; and Div. Wildlife, 1967).

Herbicides and all other vegetation control methods merely set our evolving, dynamic ecology back to an earlier sere. Plant succession is set back toward the bare-field stage and it matters little whether by herbicides, cow, plow, bulldozer, axe, or fire. Under normal usage herbicides are not reapplied to the stage of the bare field. Actually, the lesser vegetation (forbs and grasses) is seldom greatly altered when trees are killed in spraying operations. Plant competition and succession may well change vegetation in some unexpected ways in some locations. These may be difficult to predict in ecologically poorly known areas such as Southeast Asia. However, the recent, comprehensive studies by Llewelyn Williams on the vegetation (1965) and forest types (1967) have contributed immensely to our understanding of that bioclimate's plant ecology. These studies merit extension. Similar extensive efforts must now be undertaken to study the animal ecology of that area.

Unfortunately rare species usually need cover as badly as food production and although some grasses and browse species may increase, the net effect of jungle destruction will be negative as far as the rare forest animals enumerated above are concerned. The amount of leaf defoliation and tree kill through herbicides is the critical factor. The elimination of food through extensive destruction of forest lands (Ziswiler, 1967) or other habitat will quickly wipe out endangered animals. Specifically, the elimination of jungle habitat in large blocks can be expected to affect leaf eaters such as langurs and the more omnivorous gibbons.

Though marginal, some actions have been taken to protect the wildlife in Southeast Asia and South Vietnam in particular. Boyle (1962) reported that a national commission for nature protection had been set up in South Vietnam. The chairman of the commission, who is also the Director of Waters and Forests in SVN, is responsible for the application of the Commission's programs. These include wild life protection, soil conservation, nature education, and the creation and organization of reserves and national parks.

More recently, Fitter (1965) stated that some encouraging news from Southeast Asia was reported by Dr. Boonsong Lekagul, New Road, Bangkok, Thailand, a member of the Survival Service Commission of IUCN, in Conservation News of which he is editor. He reported that in Cambodia, five wildlife refuges have been set up under the Service des Eaux et Forets, one of which is designed especially to protect the rare wild cattle of Cambodia, the Kouprey. This is the Koulen Prom Tep Refuge of nearly one and one-half million hectares in the northeast. As well as Kouprey the refuge harbours elephants, gaur, banteng, buffalo, brow-antlered deer, hog-deer, tigers, and leopards. "Properly managed," says Dr. Boonsong, "it would be the richest game preserve in Southeast Asia."

In Indonesia, Mr. Hasan Basjarudin, Director of Forestry, has organized a Division of Nature Conservation and Wildlife Management in the Forest Department. An Academy of Nature Conservation has been established at Bogor within the Agricultural Academy to secure the necessary training for the staff. The first graduates from a conservation course at the Forestry School in Bogor are now working in field conservation posts. Current plans call for the establishment of a National Council on Nature Conservation, in Indonesia (Jenkins, 1967).

Most studies have not shown herbicides to be directly destructive to wildlife but indirect effects may be of benefit or harm (Springer, 1957). As with fire, herbicides may be used to increase wildlife food production (Krefting et al., 1960). There is little direct effect of herbicides on animals because residues in vegetation are of a very low order. Ordinarily herbicides do not concentrate in animal tissue (except briefly for silvex in fish), as do some of the chlorinated insecticides.

Wildlife biologists have found pressing problems posed by the persistent insecticides such as the organo-chlorine chemicals, e.g., DDT. These should not divert attention from other more subtle pesticides, particularly herbicides. Although most of them are only slightly toxic to birds, they may have a considerable effect on bird populations by affecting their food supply. They probably have a great effect on flowering plants and so indirectly on insects. It has been suggested that this raises a difficult problem for conservationists. It is reasonable to object to the direct poisoning of birds by insecticides, but much more difficult to object to herbicides which, by controlling weeds and other seed producing plants efficiently, reduce the amount of food available to birds (Jenkins, 1967, & Linduska, 1964).

Herbicides are comparatively new means of vegetation control. The most widely used are the chlorophenoxy compounds. Not only have these been used to kill plants but they have also been used in many other ways: the rooting of cuttings, fruit set, control of pre-harvest fruit drop, control of flowering time, ripening of fruit picked green, the stimulation of ovary growth, etc. The effectiveness of these compounds on plants is so varied and dependent upon so many outside influences that generalities are impossible. Some plants are killed outright; others will be top-killed and resprout from dormant buds at the base; others will be defoliated and leaf out within a few weeks or the next season; some are not affected at all; and still others are even stimulated by the application of herbicides. The percentage of kill is dependent upon the time of year the application is made, upon the general vigor of the plant, the concentration, formulation, and amount of the herbicide applied.

Egler (1950) said, "Experience with 116 species of herbs, shrubs and trees on this property (Aton Forest, Northwestern Connecticut) indicated that it is entirely feasible and practicable to produce and maintain a variety of seminatural herbaceous and shrubby plant communities derived from scrub and old fields. Ninety-eight percent of the control of unwanted 'weeds' can be affected by the use of the chlorophenoxy compounds that are already available, and through normal competition for light and space from unsprayed or resistant plants. Only grasses and Juniperus communis showed no reaction whatever to the herbicide." In the text of this paper, Dr. Egler lists the species treated with the method of treatment and the results on each of them.

Many studies have been made on the use of herbicides, phenoxys particularly, in range control and improvement. Fisher et al.,(1959) lists the results of various treatments for the control of mesquite and post-application practices for the maintenance of improved areas.

Kirby et al. (1967) reports the effects of various herbicides and methods of applying them on winged elm in brush control in Oklahoma. Lehman and Davis (1967) also reported on the use of herbicides to control winged elm in Texas.

Other studies have been made on poison oak, blue oak, cedar elm, ragweed, aspen and several other species of plants. The results of the effects of various herbicides on these "target" plants are well documented. There is little known or reported on the effects of other plants in the community.

Two very interesting series of studies are worth mentioning since they appear to have a more far-reaching effect than just the elimination of some weeds.

In many of our coniferous forest communities where fire has been an accepted factor of the environment, certain very definite ecological seres (stages in the formation of a mature, climax forest) have been observed. In Michigan and Minnesota the dominant species of the Great Lakes coniferous forest are the red pine and the white pine, in association with these is a much smaller jack-pine. After a fire has swept through the area, cones which have been hanging on the jack-pine, unopened for several seasons, open and shed great quantities of seeds which are blown by the wind into the denuded areas. Large-toothed aspen also growing on the fringes of the forest also invade very quickly. The aspen grows far more rapidly than do the pine seedlings and form a shade canopy over them. Behind the jack-pine, the more important but still slower growing red and white pine seedlings move in. In the normal sequence of events, the jack-pine, after several years, will break through the canopy of aspens and eventually crowd them out to the fringes of the area. Several years later the much larger white and red pine break through the canopy of jacks, relegating them to a very minor role until their characteristic fire-opened cones are again needed.

Forest-management personnel have found that it pays dividends to "release" the pines from the aspen cover years before they would normally breakthrough. Yields were often better and more quickly attained. Yet, this had its problems too. The deer of this forest ecosystem used the aspen as a major source of browse. By careful experimentation on when and what concentrations to use, it was found that the aspen could be induced, after top-kill, to sprout from the base, increasing the amount of young browse within reach of the deer. The dead trunks, which were left standing, soon became infested with insect larvae and in the process of decay became very good feeding grounds for the bear. The clearings that resulted also improved conditions for the grouse (Schacht and Hanson, 1963). Similar studies have been made regarding antelope and elk.

Sagebrush (Artemisia), has invaded the grasslands in the arid regions of Colorado and Wyoming as a result of overgrazing and the prevention of grass fires. In an attempt to control the sagebrush and to restore better grazing lands it has been found that often instead of the grasses moving in to replace the sagebrush, the weedy pioneers that make the initial ground cover are bitterweed (Hymenoxys) and broomweed (Buttierezia) both of which are less desirable than the original sagebrush. In Figure IX-10, which clearly illustrates this succession phenomena of revegetation following physical control (grubbing) of big sagebrush in New Mexico, the broomweed infestations of

Photograph by R. W. Mitchell, courtesy McGraw-Hill and World Book Encyclopedia

Figure IX-10 - Contrasting Secondary Successions

Source: Allen, D. L., The Life of Prairies and Plains, McGraw-Hill Book Company, New York, pp. 144-145 (1967) the grubbed portion of the range is clearly shown on the left of the photograph. Both are, however, replaced by the desired grasses, particularly if planting of these grasses immediately follows employment of the vegetation control method. These revegetation-succession phenomena occur in chemically controlled ranges also.

One indirect effect that is also of ecological significance is the biocoenosis--sagebrush-sage grouse. Studies have shown that during nine months of the year the sage grouse must rely on the sagebrush for about 96% of its total food. As the sagebrush has extended its range so has the sage grouse. The converse is also true: as the sagebrush is pushed back or eliminated, so is the sage grouse.

The game-management divisions of both Colorado and Wyoming have been actively studying this specific biocoenosis for a number of years. Recently, the Western States Sage Grouse Committee has resolved and established an excellent set of guidelines to assist those planning sagebrush-control programs (Swope, 1965-1967). These certainly will serve as a model for other plant-animal biocoenosis resolutions for the improved practice of chemical-vegetation control on multi-use land.

The regulation of sagebrush control as a function of ground cover remaining has several important ecological facets. As depicted in Figure IX-11, a 20% reduction in sagebrush cover over a period of five years of chemical control has resulted in an expected corresponding increase in grass cover. But most important ecologically are the facts that: (1) the total forbs, which contain the extremely important legumes responsible for nitrogen fixation, have decreased only slightly under this regimen and (2) the erosion hazard, as indicated by the data on "bare areas," has also been kept under control.

There are other fauna whose requirements are as exacting as, or even more than, that of the sage grouse. Very little work has been done to see what really happens to the entire ecosystem if its base (i.e., the primary "plant" producers) is modified to any extent at all.

The effect of herbicides on fauna is basically an indirect one. The death of plants removes the source of food and also nesting sites and cover (habitat). If the animal can utilize another plant for food, the damage to that species is slight. The degree of dependence upon the particular plant that is killed determines the extent of damage to the faunal species.

Day (1967) has recently observed that this problem is one of taxonomy rather than ecology. The first part of a study of any ecosystem must be taxonomic, in that it is first of all necessary to know what organisms live in the community. But just to know the organisms does not mean, under any circumstances, that the interrelationships within the community are understood.

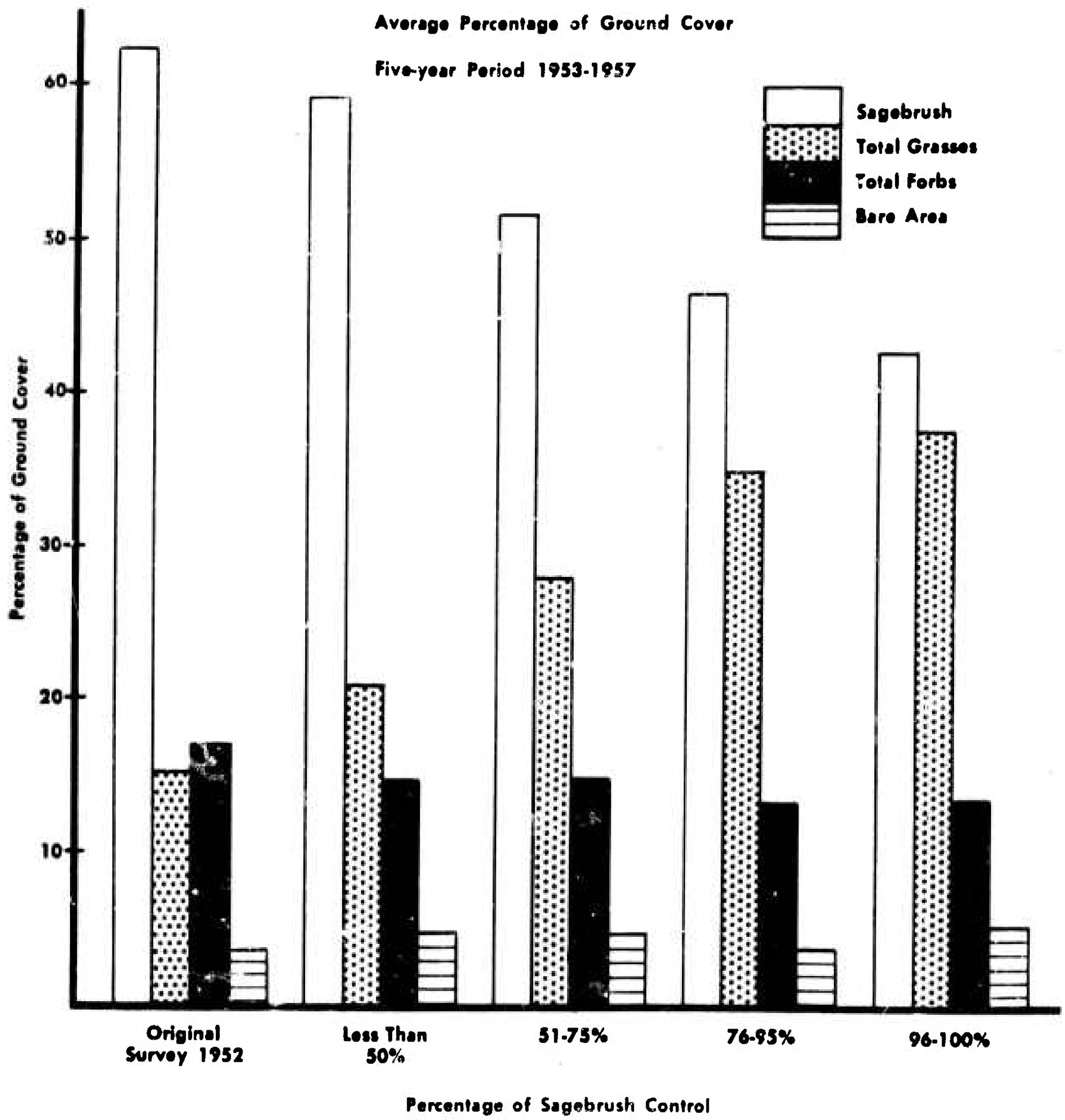


Figure IX-11 - Chemical Control of Big Sagebrush

Source: Alley, H. P., and D. W. Bohmont, "Big Sagebrush Control," Agric. Exp. Stat. Bull. 354, University of Wyoming, February 1958.

As stated earlier (p. 263, Section "C", this chapter), Ovington (1962) found it impossible to describe the many interrelationships which exist in a natural woodland ecosystem. Nevertheless, the undertaking of baseline ecosystem studies from a community economics viewpoint is productive and essential to our understanding of the complete, dynamic ecosystem.

E. Ecological Effects on the Abiotic Factors

Soil Erosion

In assessing the consequences which may result from extensive use of herbicides on an ecosystem, one must consider the indirect effects of herbicides on soil erosion. The unquestionable fact is that our ecology is "rooted" in the soil. The existence and the fertility of this edaphic factor are paramount to our very existence. Our concern here is with the indirect effects of herbicides in the soil-weather-plant-herbicide-man complex. Only those aspects of soil erosion which relate to the ecological consequence of the use of herbicides will be discussed here. Although pertinent, a summarization of soil science (pedology), soil-forming processes, and agronomy will not be presented in this report except as necessary to understand the relationship of certain soil characteristics and herbicide effects. Furthermore, we must confine ourselves to a discussion of man-induced erosion and aggradation in relation to the "natural" modification of geological parent materials under different climates and on different topographies. Wherever possible, provided the information is available, a comparison of pertinent herbicide effects to those resulting from other land management practices will be made.

However, prior to discussing any effects, it will be necessary first to define some basic terms employed. Using the broadest sense generally acceptable and in keeping with the geomophological view that land forms are parts of evolving systems adjusting to given sets of environmental factors, the following definitions pertaining to soil erosion have been employed in this report. According to Strahler (1956), erosion is the progressive removal of soil or rock particles from the parent-mass by a fluid agent. Gully (channel) erosion is the cutting away of beds and banks producing gullies and deep shoestring rills into previously smooth slopes and valley bottom stream channels which contained the flows at all but the highest flood peaks. Sheet (slope) erosion is the relatively uniform reduction of a fairly smooth ground surface under the eroding force of overland (sheet) flow, where such flow is generally characterized by being continuously spread over the ground and not engaged in carving distinct channels into its surface. Aggradation results from water and wind erosion and all of the basic forms thereof, and also indirectly from sun erosion (i.e., the lack of water). It is the deposition or accretion of soil particles on the lower parts of valley side slopes and the channel floor. The extended alluvial deposits which are spread broadly upon alluvial fans and flood plains are a long-term effect of aggradation The so-called "accelerated erosion", which is that induced regimen attributed to the meddling of mankind in his environment, has received the brunt of the concerned, forecasting a barren, infertile and humanly overpopulated future environment (Sears, 1956; McNeil, 1964; Whitten, 1966), Figure IX-12.

Dr. Boysie Day has said (Day, 1966),"that man as a species survives in large numbers only because he has denuded much of the earth of natural vegetation and substituted crop plants grown in monocultures." Such man-induced landscapes are, ecologically, very nearly bare areas, subject to soil erosion and invasion of weeds. Nevertheless, when the "natural" cover of the landscape is removed without providing a substantial artificial equivalent, the rate of erosion is accelerated. The resulting soil impoverishment depends on several factors, especially how long and in what way the area has been denuded and/or cultivated, whether or not it has been burnt and the quantity of debris or slash left on the ground after clearing. Obviously, these factors are interdependent with the local conditions of climate, topography, soil type and the degree of humus destruction.

Since the agricultural losses ($3.8 billion/year) caused by weeds in the United States are believed to equal the combined losses from insects and disease and to rank second only to those caused by soil erosion, man as an affecting agency has attempted for centuries to eradicate weeds by various means (King, 1966; Saunders et al., 1962). The eradication of specific plant species by man initially involved physical control methods such as cutting, burning, tillage and mulching. The intentional selective denudation of the landscape by employing these physical weed control methods quickly led to serious soil erosion, primarily characterized by aggradation, under the combined forces of water and wind. In 1944, prior to the large scale application of chemical herbicides for agricultural practice, Hanson (1944) said, "Let us not forget that in our anxiety to exterminate this menace (weeds), we may be guilty of encouraging the ravages of the worst enemy that the farmer can have - soil erosion." He pointed out that the practice of bare fallow for bindweed eradication led to serious soil erosion problems which could be controlled by utilizing the new technique of subsurface tillage for bindweed removal. A decade later, Shafer (1954) reported that the repeated complete tillage for the control of such deep rooted perennial herbaceous weeds such as bindweed and Canada thistle in growing crops often led to severe soil erosion where those potential hazards existed. He showed that the application of 2,4-D at rates up to and including 120 lb/acre were required for the effective control (90%) of Russian knapweed. This higher application resulted in less soil erosion than when physical control methods were used.

Figure IX-12 - The Copper Basin at Copperhill, Tennessee, is Suggestive of What Land Without Life Would be Like. A luxuriant forest once covered this area, until fumes from smelters killed all of the vegetation. Although fumes are no longer released by modern methods of ore preparation, the vegetation has not become re-established. (Courtesy U.S. Forest Service)

Agencies other than man, such as natural fire, excessive trampling from wildlife, and burrowing of animals, have caused bare soil through uncontrolled landscape denudation (Piemeisel, 1938). Although soil erosion resulting from weed eradication by any method has not yet been as severe as the infamous copper basin at Copper Hill, Tennessee, complete denudation and severe gullying has resulted from various land management practices. For example, in controlling sagebrush on rangelands in the United States, the potential erosion hazards have been clearly pointed out by Pechanec et al. (1954). Table IX-2 taken from their bulletin summarizes the limitations and advantages of the seven most common methods of big sagebrush control (i. e., planned burning, plowing or disking, railing, harrowing, beating, grubbing, and spraying herbicides). The proper application of herbicides for big sagebrush control on rangeland decreases both wind and water soil erosion hazards. However, complete denudation of rangeland by any means including herbicides will result in an increased hazard for wind erosion and if used on slopes of greater than 30% the water erosion hazard is also extremely increased. Nevertheless, the erosion hazards are not normally increased by the proper use of herbicides on this ecosystem. The dead standing brush, undisturbed litter cover and undisturbed soil and grasses do not generally tend to favor erosion. But the widespread spraying of sagebrush should be undertaken with caution. The lack of knowledge regarding effects of herbicides on associated desirable broadleafed forage plants and shrubs and upon the associated food chained animal life gives further reason for this caution.

Wiese (1960) has also shown that the use of herbicides to effect chemical fallow in cropland has reduced the soil erosion hazard from both water and wind. Furthermore, the continuing development of newer herbicides has enabled the concomitant use of synthetic mulches to improve soil structure and assist moisture penetration. This reduces water runoff and deters wind erosion, thus decreasing soil losses from the ravages of water and wind.

In tropical areas of the world, herbicides are being used to an increasing extent to control and manipulate vegetation. Specialists in brush and weed control encourage the use of herbicides to replace older and less effective methods of land conversion (Furtick,1967).

On the African savannah, Holm (1967) indicates that the traditional practices of overgrazing, trampling and poor management of fires not only encourages growth of "bush" but brings on erosion. Mechanical removal of brush is costly and does not give lasting control. Chemical control with selective herbicides has given effective brush control, and has also helped reduce the tsetse fly population thereby providing some control of certain disease epidemics.

TABLE IX-2

SUMMARY OF LIMITATIONS AND ADVANTAGES OF THE SEVEN MOST COMMON METHODS OF BIG SAGEBRUSH CONTROL

Item	Method of Control[a]: Planned Burning	Plowing or Disking	Railing	Harrowing	Beating	Grubbing	Spraying D/T[b]
Kill of big sagebrush	95 to 100% of all ages	70 to 99% of old; slightly less of young	30 to 80% of large old; 15 to 50% of young flexible.	30 to 70% of old brittle; 10 to 30% of young flexible.	50 to 90% of large old; 30 to 60% of young flexible.	90 to 99% for all age classes.	70 to 95% of large old; slightly less of young.
Kill of associated undesirable plants.	Not effective on sprouting shrubs and some annuals.	Usually not effective on sprouting shrubs; good on cheatgrass.	Not effective on sprouting shrubs or annuals.	Not effective on sprouting shrubs or annuals.	Not effective on sprouting shrubs or herbaceous species.	Effective on shrubs if cut 4 to 5 inches deep; on annuals at a shallow depth.	Not satisfactory with rabbitbrush, horsebrush, or cheatgrass.
Effect on desirable forage plants.	Low kill of grass, 30 to 40% loss in vigor first year. Nonsprouting shrubs killed.	Kills all except those that sprout or spread by rootstocks.	Damage slight except for pedestaled grasses and nonsprouting shrubs.	10 to 20% of bunchgrasses uprooted; damage to bitterbrush slight.	No serious damage to herbaceous plants; nonsprouting shrubs damaged.	Rhizomatous[c] grasses little damaged; bunchgrasses killed except where cut deep in moist soil.	Grass not damaged; many forbs and nonsprouting shrubs may be damaged.
Ease of seeding after treatment.	Easily done with drills; firm seedbed.	Easily done with drills; seedbed may be loose.	Not easily drilled unless piles of brush burned. Poor covering for broadcast seed.	Seed broadcast ahead of harrow well covered; drilling difficult.	Can be drilled unless brush heavy; broadcasting before often successful.	May be necessary to clear brush before a drill can be used.	Standing dead brush may be barrier to drilling.
Adaptability to terrain and soil.	No limit except as imposed by fire danger and erosion hazard.	Limited to little or no rock except with brushland plow.	Breakage high where large, embedded protruding rock occurs.	Primarily suited to quite rocky ground and rough terrain.	Limited to rock-free or slightly rocky sites.	Limited to level and rock-free areas.	Virtually unlimited.
Availability of equipment.	Equipment needed generally available; experience primary need.	Plows and disks commercially available; Brushland is custom made.	Not commercially available; easily built in farm shops.	Not commercially available, can be built in machine shops.	Commercially available.	Commercially available.	Commercially available.
Effect on erosion hazard.	Exposes soil, destroys litter; avoid high hazard areas.	Exposes soil to moderate degree.	Debris left protects soil except in spots.	Usually decreases hazard.	Mulch left may decrease hazard.	Slight if any.	Slight if any.
Cost of control (1952 costs).	$0.50 to $2/acre on tracts of 1,000 acres or more.	$3 to $5/acre.	$0.50 to $1/acre one-way on large tracts.	$3 to $5/acre.	$7 to $8/acre.	Approximately $6/acre.	$3 to $6/acre.

a/ Other less effective, specialized methods include: mowing, ripping, flooding and use of rolling brush cutter, road graders and bulldozers.
b/ D/T only: ground and aerial application of 1 - 2 lb. i-propyl or butyl ester of 2,4D and/or 2,4,5-T per gal of water:oil - 4:1.
c/ Sprouting from roots or spreading from rootstocks.
Source: Modified from Table I, p. 12 and 13, J. F. Pechanec, et al. (1954).

While soil erosion may occur anywhere the earth is exposed to weathering, the process of laterization is characteristic of the moist tropical regions (Figure IX-13).

The soils of rain forest areas are quite variable in physical and chemical properties but share many similar characteristics. High and relatively uniform temperature promotes rapid microbial decomposition of leaf litter and other forest debris. The soils are invariably acidic, with relatively low humus content, and are often deficient in plant nutrients. The high temperature and abundant rainfall produce almost continuous downward movement of water through the soil, resulting in heavy leaching. Silica and other minerals are removed, leaving typical red or yellow soil rich in iron oxide and alumina, called latosols (Figure IX-14). Latosols (often called lateritic soils) occur most frequently in the tropical belt within 30 degrees of the equator. Various latosols are the most extensive soil types found throughout Southeast Asia. Laterization is of special concern because these soils when exposed and dried are converted into hard red rock called laterite (from the Latin word for brick or tile). The term laterite is applied as the end result of laterization--a mixture of alumina and iron oxides with very little else. This end result is never reached under a cover of rain forest. Lateritic soils may develop under glassland, savannah, or forest. Under the forest, however, the concentration of iron and aluminum compounds occurs at some depth from the surface, while under grassland it occurs at the surface. Clear-cutting the forest and converting the area to grassland, though, may result in accelerating the hardening of lateritic soils into laterite rock, a process which greatly lowers the productive capacity of the site (Spurr, 1964).

According to McNeil (1964), "laterization of soil throughout the tropical belt is still taking place and the intervention of man now threatens to accelerate the process on a large scale." At Iata in the Amazon Basin, the land was deforested and bulldozed for an agricultural colony. What appeared to be a rich soil, with a promising cover of humus, disintegrated after the second planting. Under the equatorial sun, the iron-rich soil began to bake into brick. In less than five years the cleared fields became virtually pavements of rocks.

While less dramatic, the process of shifting agriculture (or "Rai") practiced throughout Southeast Asia tends to destroy soil productivity in much the same way. Thousands of acres of forests are burned each year, followed by planting field crops on a few hundred acres. After two or three crops, the patches are abandoned, and grasses, vines and bamboo take over. It is reported (Williams, 1965) that the inhabitants of a single village may destroy a complete forest within a radius of 15 miles. Large areas which are cleared, as for plantations, are often permanently lost to agriculture after a few

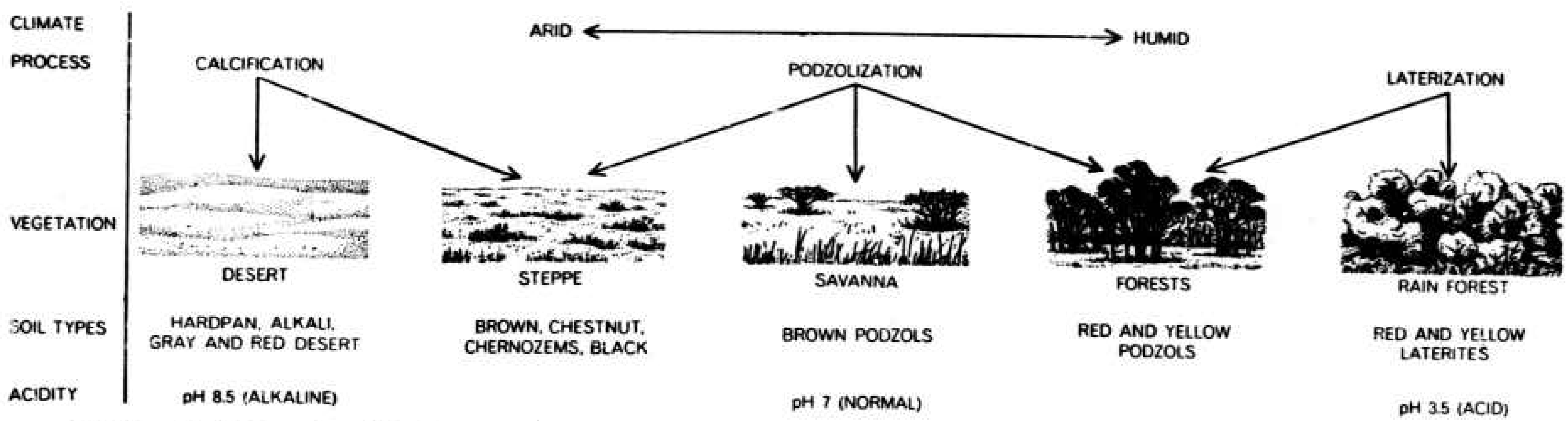


Figure IX-13 - Soil-Forming (Weathering) Processes. The spectrum of soils ranges from dry to wet and alkaline to acidic. The method of formation is indicated by the arrows; the characteristic soil of steppes, for example, is produced through a combination of calcification, which is an accumulation of hardened carbonates, and podsolization, which is a leaching of the upper layers. Lateritic soils usually lack a hardened layer of accumulated carbonates. Weathering under certain conditions of soil climate, which are found in the tropics, produces lateritic soil.

Source: McNeil, M. "Lateritic Soils," Sci. Am., 211, (5) pp.100-101, November (1964)

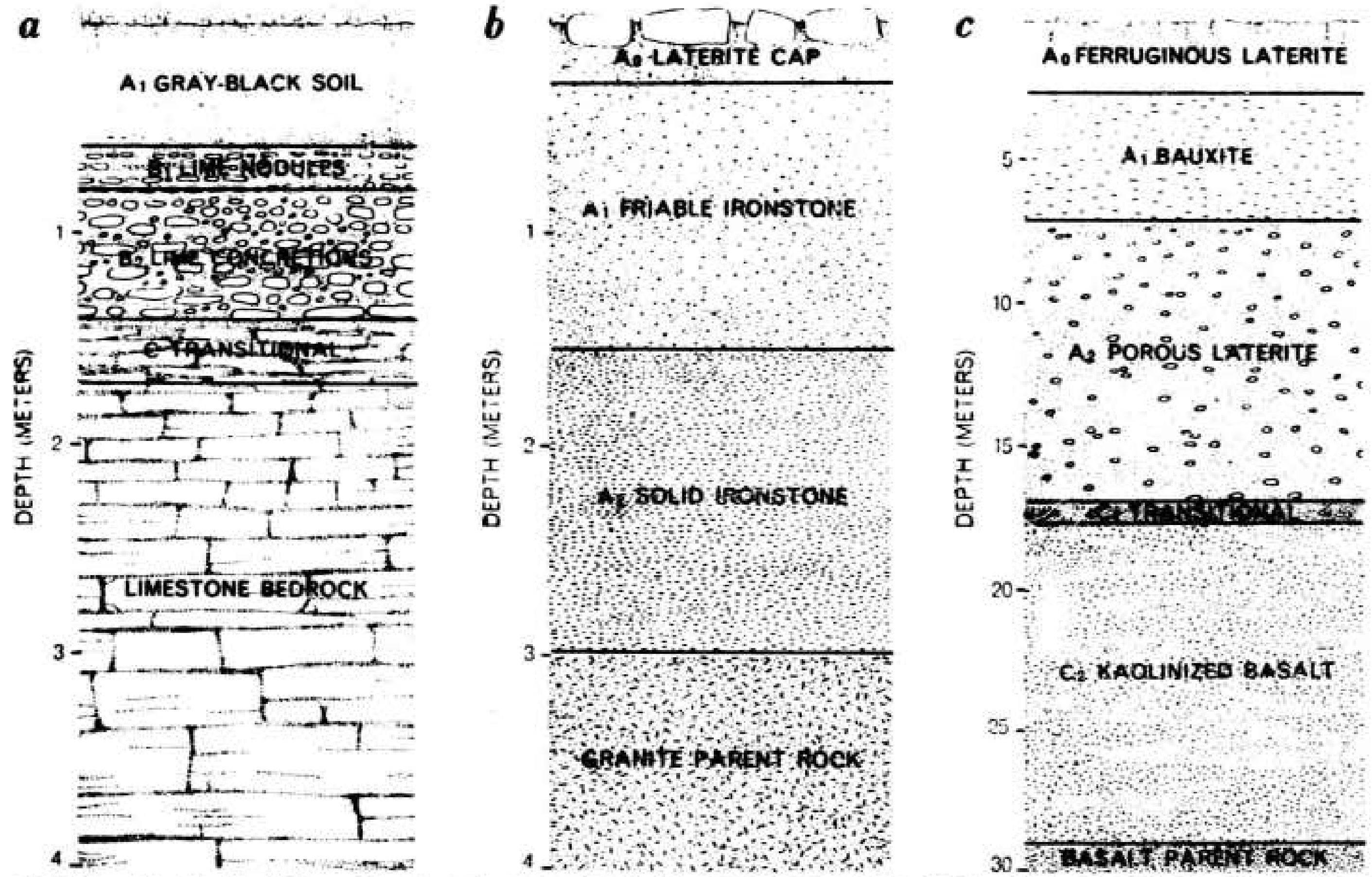


Figure IX-14 - Soil Profiles Contrast a Typical Temperature Zone Soil (a), as Found in Northern India, with Lateritic Soils as Found in DaHomey, West Africa (b), and in Southern India (c). Letters at left identify the principal soil horizons, or layers, as usually classified by soil experts. Temperature Zone soils normally have organic material in horizon (A); in lateritic soils that material has been leached away.

Source: McNeil, M., "Lateritic Soils," Sci. Am., 211, (5) p. 100, November (1964) crop cycles have worn out the soil. Except for the lowland fertile plains of the Mekong and Tonkin Deltas, most of the land area of entire Vietnam is not considered suitable for intensive cultivation (Williams, 1965).

While the Mekong Delta soils are primarily alluvial due to recurrent flooding, laterite soils occur in this region also. According to Duke and Mussell (1963) about 4% of the Mekong Delta in Southeast Asia is composed of lateritic swamp. If denuded and dried, much of this soil could be irreversibly converted to laterite. The forces of nature intervene to prevent such soil changes. Each year the growing of crops depletes the highly leached soil of this rainy valley. In the monsoon season, the overflowing rivers of the system flood the land and replenish it with a new layer of silt. If the annual floods are stopped by presently proposed river plans (White, 1963), the soils of the region may be drastically affected (McNeil, 1964).

Furthermore, the soils north of the Mekong Delta in the Annamite chain of mountains of South Vietnam are characterized by a transitional area of flat to rolling topography bearing uplifted podzolized alluviums and reddish latosols. And in the Annamite chain extending into North Vietnam, the soil types are a complex of red and yellow podzols and lithosols (Duke and Mussell, 1963).

Therefore, it would appear geologically that the weathering and soil formation processes of the area under question, i.e., the South Vietnam soils, are podzologenic as well as laterogenic.

At the time of this writing, we do not feel that we have sufficient information on the soil conditions of all of Vietnam to draw any valid conclusions covering the hazard of creating laterization of soil by the indirect action of herbicides.

We do know by consulting with observers that have been in the sprayed zone, as well as from herbicide application experience in this country, that all the ground cover is not destroyed and the recovery of vegetation is very rapid under the climatic conditions of that country.

Hydrology and Climate

The climate, microclimate, weather and hydrologic factors of an ecosystem must be considered in any attempt to assess the ecological consequences resulting from the indirect effects of extensive herbicidal treatment of bioclimates. There appears to be some controversy concerning the generally accepted, broad climatic-climax vegetation principle. However, there are some examples of climatic alteration due to elimination of vegetation. The annual rainfall decreased on the deforested plains of Spain.

The Copper Basin with its 7,000 acres of bare area is the largest denuded area in any semi-humid region in the U. S. (Tennessee). This denudation was caused by fumes from the open air roasting yards of copper smelters. The fumes brought about a defoliation and subsequent death of trees, grass and weeds on more than 25,000 acres (about 40 to 50 square miles) of land. The bare area is surrounded with a grassy strip. In a transitional ring about the grassland is a zone of sparse trees, shrubs and grass, covering approximately 30,000 acres. Beyond this area are thick forests.

Data of an exploratory nature were collected from the Copper Basin during four consecutive years, 1936-1939. This study indicated that removal of the forest cover has subjected the soil to higher summer temperatures and to greater temperature fluctuations throughout the year.

Higher soil temperatures (22°F higher than the forest zone) during the growing season affects other elements of the local climate--soil moisture and evaporation.

The wind velocity in the summer was 13 times greater on the bare area than in the forest area.

The monthly evaporation rate was five times greater in the bare zone than in the forest.

In any six-month period of the four years of record, regardless of season, more rainfall was measured in the forests than in the grass or bare regions.

The grassed area receives more rain than the bare zone in every month of the year.

In the months of September and October, the grass zone has a slightly higher rainfall than the forests.

It was concluded that because of the topography, the location of rain gauges, wind velocity or vertical eddying influences; that it was impossible to arrive at a firm conclusion about the effect of loss of vegetation on rainfall in the Copper Basin (Ingersoll, 1964).

The Copper Basin is one example of an immensely altered ecological area.

Climatic data should be evaluated in the areas where cities have grown rapidly to determine what changes have taken place in rainfall levels and temperature ranges.

The indirect effects of using vegetation control chemicals have been examined in respect to the hydrologic cycle. Some examples follow:

1. Increasing usable water yield (Merriam, 1961, and Reinhard, 1965).

2. Increasing ecosystem's moisture-holding and retention capacities (Sonder and Alley, 1961).

3. Eradication of phreatophyte (salt cedar, etc.) infestations in attempts to reduce consumptive waste of water (Powers and Hamilton, 1961, and King, 1966).

4. Increasing swamp drainage in watershed developments (Barick, 1966).

The use of herbicides for these purposes listed above causes specific effects of ecological consequence. Mainly in that the dynamics of the hydrologic cycle (see Figure IX-15) are altered in a beneficial manner, water is conserved or swamp drainage is improved. In the latter instance, the wildlife habitat is altered.

The extensive deforestation (bare earth) of tropical rain forests for agricultural development (Pendleton, 1939) without regard to the ecological aspects promotes accelerated soil erosion. When activities of this nature are not accompanied by a balanced revegetation program, significant change in the climate may result (Sopper and Lull, 1965).

The climatic-climax-vegetation concept has been questioned (Sauer, 1950); but since this ecological phenomenon is still generally accepted, the corollary must also be considered. If an ecosystem's vegetation is destroyed to such a degree that there is a resultant decrease in the evapotranspiration within that system, the macroclimate of that area may eventually be significantly altered.

It is of importance to determine what degree of climatic alteration occurs when large areas are treated with vegetation control agents. In this instance, bare earth does not occur unless large amounts of herbicides are used to sterilize the soil as for industrial site clean-up. A factor of considerable importance would be the revegetation rates and the degree of ground coverage.

Our conclusions regarding the ecological effects of using vegetation control chemicals and some of the possible consequences associated with their extensive use in the environment are presented in the following chapter.

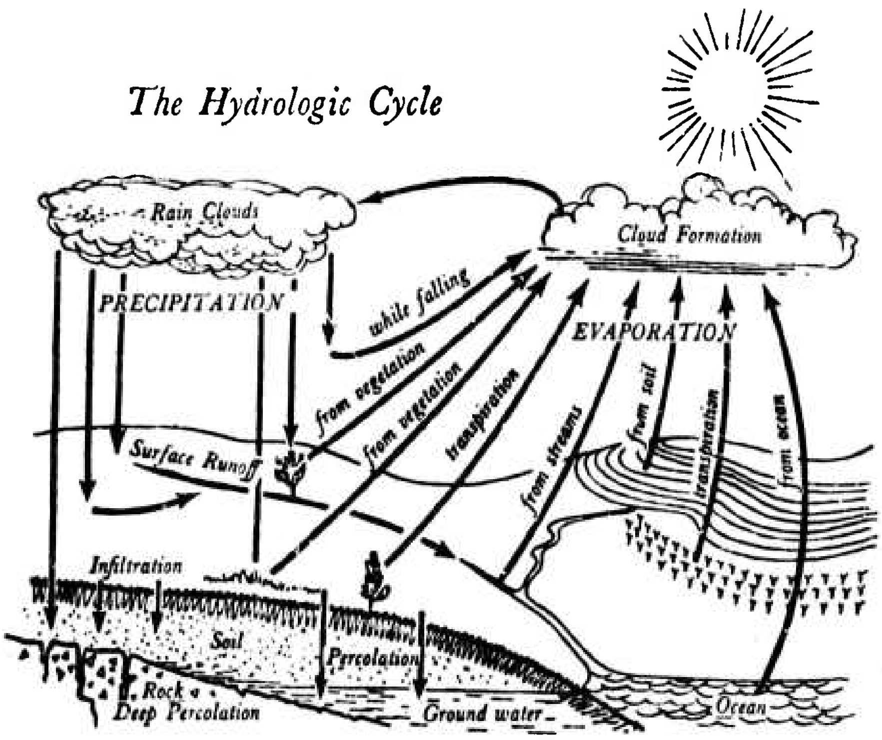


Figure IX-15 - Diagrammatic Representation of the Hydrologic Cycle

Source: The Yearbook of Agriculture (1955).

X. AN EVALUATION OF SOME OF THE MAJOR ECOLOGICAL FACTORS INVOLVED IN THE USE OF HERBICIDES

The objective of this report is to assess the ecological effects of extensive or repeated use of herbicides. The basis for this assessment has been made by a critical evaluation in the following sectors:

1. A survey of the uses and common practices employed in vegetation management as applied to noncroplands and aquatic environments.

2. A survey of the use of herbicides as a military weapon.

3. A survey of the toxicology of the herbicides on a broad spectrum of organisms.

4. A survey of the residual nature and persistence of herbicides in soil, vegetation and water.

5. A review of some of the factors involved in determining the fate of herbicides in soil, vegetation and water

6. A review of the more important ecological factors involved in the use of herbicides as related to their effect in ecosystems and various abiotic factors.

As a result of these efforts, an attempt has been made to express our findings in the following manner:

1. What judgments about the impact of herbicides on the ecology can be formed?

2. Which areas of inquiry are so inconclusive that reliable judgments cannot be made?

A study of the effects of herbicides or any other disruptive phenomena on the ecology of an area involves a multiplicity of factors that in the final analysis must be dealt with on a broad and qualitative basis. This restriction is not one of choice but has to be accepted since the science of ecology has not reached maturity. Maturity is used here in the sense that an ecosystem cannot be completely defined within the scope of the present definition of ecology. This in no way implies that there is a lack of progress or that the study of ecology is not extremely important. A wide acceptance of the importance of ecological approaches to environment problems is needed. Although many studies have been carried out by ecologicts, even more studies have been done by investigators who are trained primarily as plant physiologists, agronomists, wildlife managers or foresters and may include many other branches of biology. Investigators with these types of backgrounds became interested in the applications of some of the principles of ecology as related to the problem of their particular interest.

The relating of multiple variables for quantification of an ecosystem is a formidable task. The science of ecology suffers from the inability to project a long-range view quantitatively with any degree of certainty as to the total development or outcome of an ecological disturbance.

In the process of civilization's advancement, we have engaged in activities with immediate cost benefits in view, such as the cutting of forests and the plowing of the land. No one will deny that all of these things come into practice to serve a human need. If there is any doubt whether these practices were judicious or not, we only have to re-orient our thinking and assess the consequence of not removing forests on many areas or not plowing up the land. Ecologically (and economically) problems can be brought about by refraining from doing things just as well as by overt action.

Conservationists and regulatory agencies of the government have been concerned for some time with the problems that have developed from the use of pesticides. This concern has been felt for many valid reasons; for example, the residual nature of chlorinated hydrocarbons (such as DDT) and the instances of application of insecticides over large areas that have killed wildlife and aquatic animals. There has been an increasing amount of federal funds and manpower brought to bear on all aspects of insecticide use.

Herbicides have been around for 20 years, and their rate of commercial use has increased sharply in the last five years. Herbicides have not presented the problems that have been characteristic of some of the insecticides. Basically, by design, herbicides exert their primary action on relatively simple systems--plants--whereas insecticides are by design developed to produce lethality in a more complicated organism--the insect.

Within the last five years, herbicides have been used as an instrument of war. The use of herbicides in the Southeast Asia theatre represents e most widespread application of herbicides that has ever been undertaken in a brief time interval. (In terms of total acres sprayed over a longer period of time, the rangeland and pastureland areas in this country represent a much larger area.) Another factor of concern that is involved in Vietnam is the wholesale defoliation of forests, which is not ordinarily done on a large scale in this country. Vietnam represents a wide spectrum of different kinds of vegetation. The rainfall varies from 20 to 100 inches a year. The types of crops that grow there are comparable to the United States with a significant difference; a relatively high rice acreage, and a very low wheat acreage.

The military is currently using chlorophenoxyacetic acids and their esters picloram and cacodylic acid.

Some of the statements that we make here concerning the effect of herbicides on the ecology will be based on the above herbicides as well as some 20 other herbicides that are used in this country for application to noncroplands and reviewed in previous chapters.

Our studies have led us to certain judgments which we feel can be made with confidence:

1. There is no question that the greatest short-term and long-term direct ecological consequence of using herbicides in Vietnam or anywhere else is the destruction of vegetation. As long as soil sterilization is not an objective, destruction of vegetation by herbicides is a selective process, and denuded earth does not occur especially in forest spraying (40 to 75% defoliated at the end of one month). Furthermore, the end result of the use of the herbicides from an ecological standpoint represents a process that is common after uncontrolled fires, or the wild regrowth of abandoned fields, that is, the ecosystem is set back to an earlier sere. The succession of plant life that follows the use of herbicides is similar in some respects to the pattern of revegetation which has been observed when vegetation has been removed by other means.

2. Food chains for animals, birds and lower forms of animal life and heterotrophic plants will be altered.

The long-term effects on wildlife may be beneficial or detrimental. Studies in other countries have shown that herbicidal treatment of forested areas improves wildlife habitat and is favorable to animal populations. The extent and pattern of herbicide treatment in Vietnam have no precedent, therefore it is difficult to predict the effects on wildlife with any accuracy.

In many instances where the disruption of food chains has occurred due to the use of herbicides, the animals or birds involved have a restricted habitat. Their dietary dependence is usually on a very narrow spectrum of foodstuffs (for example, the sage grouse and the black-footed ferret in the United States and the Douc Langur in Vietnam).

3. The herbicides now being used in Vietnam will not persist at a phytotoxic level in the soil for a long period of time. On the basis of the average temperatures and rainfalls in Vietnam, it would be reasonable to expect that the chlorophenoxy acid esters will be dissipated quickly. Picloram

will leach into the soil perhaps even to depths of 24 to 36 inches. In areas that normally have low rainfalls (20 inches), with medium to heavy soil, the leaching of picloram will continue at a slower rate. Cacodylic acid presents no persistent phytotoxicity problem from soil residues. This herbicide is tenaciously bound to soil particles and it resists leaching. Crops can be planted without risk in a matter of days after spraying with cacodylic acid. Application of 5 lb. per acre of cacodylic acid to alfalfa and rye grass did not result in residues in the cuttings.

4. The possibility of lethal toxicity to humans, domestic animals or wildlife by use of the noncroplant herbicides discussed in this report is highly unlikely and should not be a matter of deep concern.

5. A number of insecticides (chlorinated hydrocarbons) have a propensity to concentrate in some animals or insect populations. Herbicides, on the other hand, seldom persist in animal or insect tissues. Toxic transfer to the next higher animal in the food chain is minimal. In fact, biological concentration does not occur with most herbicides, since they are readily excreted from animals.

Acute toxicity data are presently available for all the noncropland herbicides. For some, however, there is a lack of information on the effect of chronic exposure. For this reason it would be advisable to conduct feeding, teratogenic and reproduction studies for several of the herbicides, particularly cacodylic acid, before their use in a single area is continued for a prolonged period of time.

6. When aquatic weeds are controlled with herbicides the direct toxic effects on fish and bottom organisms can be relatively minor if the herbicides have been properly used. However, the indirect effects of herbicides resulting from the destruction of the vegetation may produce more important changes on the biota of the aquatic environment. Whether these changes are beneficial or deleterious depends upon a number of factors; for example, a fish such as tilapia (indigenous to Southeast Asia) would be in trouble if the herbicide destroyed the specific plants upon which this fish feeds. On the other hand, serious oxygen depletion of an aquatic environment may occur when mats of floating weeds completely cover the surface of the water and shade the photosynthetic plants in the water. In this case an important benefit to fish and other aquatic biota can often be produced through the application of herbicides for the management of fish habitat.

Areas of our inquiry that are so inconclusive that reliable judgments cannot be made are as follows:

1. An area of difficult assessment is the effect of spraying 2,4-D and 2,4,5-T esters on water quality in streams, lakes and waterways. It is impossible to draw any conclusions concerning water quality detriment without concrete data indicating the amount of sprayed chlorophenoxy acid esters that actually arrives at the surface of the water, and knowledge of water conditions.

2. There are a number of mammals and Aves in southeastern Asia area that are recognized to be in danger of extinction. Whether the application of herbicides will be the critical point in the survival of these endangered species is not known.

3. The destruction of vegetation may cause certain geographical and climatic conditions that would bring about environmental change. For instance, the average temperature of a deforested area is elevated. There is a possibility that the rainfall in that area may decrease if it is denuded of vegetation. By far, the most drastic condition necessary to bring about decrease of rainfall would be a bare earth situation. As far as we are able to judge (from the limited amount of literature in this area available to us) even if there is a recession in the amount of rainfall, it is not a drastic reduction. In fact, in at least one major study of a large denuded area, there were so many variable factors concerning the measurement of the rainfall that the differences between that area and the surrounding forest were not definitive.

4. Tropical forests in particular present a problem if the soil is principally lateritic. The removal of forest cover may result in accelerating the conversion of latosols into laterite rock, which would greatly and irreversibly lower the biotic potential and productive capacity of the treated ecosystem. We have discussed the types of soils that prevail in the tropics, including specifically the soils of Vietnam (Chapter IX). As indicated there are at least two well known lateritic swamps in the Mekong Delta and various latosols are the most common soil predominating throughout the rest of South Vietnam. We are not aware of any instances where this final and irreversible stage of the laterization process has occurred because of its acceleration by herbicidal destruction of vegetation. Observers in Vietnam have said that plant succession which occurs following defoliation of a tropical rain forest is one where the grasses cover the ground in dense stands first, and then weeds and vines become very rank in a matter of several months. Although no related evidence for irreversible changes of the abiotic factors in Vietnam exists, it is a point that deserves further consideration.

APPENDIX

Herbicide Effects on Tropical Forests (V)

Tables A-1 - A-3
Figures A-1 - A-2

Noncropland Application Levels (III-B)

Table A-4

Microbiol and Photodecomposition of Herbicides (VIII)

Tables A-5 - A-7

HERBICIDE EFFECTS ON TROPICAL FORESTS

The following general conclusions and observations are drawn from test programs conducted in Thailand[1/] and in Puerto Rico.[2/] Minimum effective defoliation is considered to be 60-65% based on visual estimates or vertical obscuration measurements.

1. Purple, Orange, and picloram are effective herbicides for long-term defoliation.

2. Cacodylic acid, paraquat and diquat are effective desiccants for fast, short-term defoliation.

3. Responses to all systemic herbicides, such as Purple, Orange, and Picloram were much better during the rainy season with its generally favorable soil moisture and growing conditions than during the dry season.

4. Minimum effective rate of Purple and Orange was 2.0 gal/acre of total esters (15 lb/acre acid equivalent) applied during the rainy or growing season. Applications at this rate were effective in both dense forest with multiple canopies and secondary forest and shrub with a single canopy. Defoliation was effective for four to six months after treatment.

5. Minimum effective defoliation with Purple and Orange was obtained with rainy season applications of 1.5 gal/acre in forest and second-shrub vegetation of light to moderate density and with a single canopy.

6. More complete defoliation and a longer duration of effective defoliation response was obtained in all vegetation types with applications of Purple and Orange at higher rates of application (2.5 to 3.0 gal/acre).

7. Cacodylic acid or sodium cacodylate applied in water solutions at rates of 5 to 6 lb/acre gave effective desiccation and defoliation of undisturbed forest and secondary forest and shrub vegetation. Maximum defoliation occurred two to four weeks after application. Treatments were equally effective during rainy and dry seasons.

1/ Darrow, R. A., G. B. Truchelut and C. M. Bartlett, Oconous defoliation test program, U. S. Army Biological Center, Technical Report 79, ARPA Order No. 423, July (1966).

2/ Tschirley, F. H., Response of tropical and subtropical woody plants. ARS, USDA Report under ARPA Order No. 424 (CR-13-67).

8. Cacodylic acid applied at 6.0 lb/acre gave defoliation response equivalent to Purple or Orange at 15 lb/acre acid equivalent.

9. Paraquat was a highly effective chemical for rapid defoliation of woody plants. In most cases, necrosis was apparent within a few days after treatment and within one week after treatment, considerable defoliation had occurred. Twenty to 30 lb/acre are needed in rain forests and 10 to 15 in drier forests with significantly less biomass. Photodecomposition of paraquat occurred readi . .

10. Diquat was equivalent in defoliation response to cacodylic acid or sodium cacodylate but was effective only during the growing season. Rates of 3 to 5 lb/acre were required for effective defoliation.

11. Picloram with few exceptions was the most effective herbicide tested for long-term defoliation of woody plants. Compared with phenoxy herbicides, picloram was more readily absorbed by leaves or roots, it was translocated more extensively and in greater quantity in the plant, it provided greater bud suppression, and was effective on a wider range of species. Treatment with 3 gal of picloram per acre (6 lb.) was as effective as 3 gal of Orange (24 lb.). However, picloram was not equally phytotoxic to all woody species and the rate required for effective defoliation varied widely. The broad spectrum of woody species susceptible to picloram makes it an extremely important herbicide for defoliation of forest types characterized by high species diversity. The most important shortcoming of picloram is that it does not defoliate most species rapidly. Orange generally gives more rapid defoliation.

12. Picloram applied singly or in mixtures with 2,4-D, diquat, and Orange was highly effective on a per-pound basis but generally slower than Purple or Orange in defoliation response. Effective defoliation was obtained with picloram in mixtures at rates of 1 to 3 lb/acre.

13. Woody plants can also be effectively controlled by making herbicidal applications to the soil. Vegetation control can be obtained for relatively long periods of time if enough herbicide is used and there is not too much rainfall. Ten pounds per acre of picloram, fenuron, bromacil and prometone will give effective woody plant control in dry areas. In wet areas, 27 lb/acre, or more, is required and picloram was the only herbicide proven to be effective.

14. The percentage of spray penetration through forest canopies was inversely related to canopy density. In a dense, two-storied forest, about 80% was intercepted by the top story and an additional 15% by the middle story, leaving 6% for vegetation on the forest floor.

15. Optimum droplet sizes for rapid fallout and best penetration proved to be in the range of 275 to 350 μ MMD.

16. Good penetration of sprays, and therefore, most effective defoliation responses were obtained more readily on shrubby secondary forest than in a dense, undisturbed forest with multiple canopy.

17. Maximum defoliation responses of 85 to 95% were recorded, but complete defoliation of all species was not obtained in any plot.

18. Secondary growth following defoliation occurs rapidly in wet tropical environments. Significant regrowth occurred six months after herbicidal treatment of foliage, and 12 months after application to the soil. Grasses, sedges, and vines are the first components of secondary growth and some woody seedlings appear soon thereafter.

TABLE A-1

INITIAL AND MAXIMUM HORIZONTAL VISIBILITY RESULTING FROM APPLICATIONS OF PURPLE, ORANGE, AND OTHER DEFOLIANTS

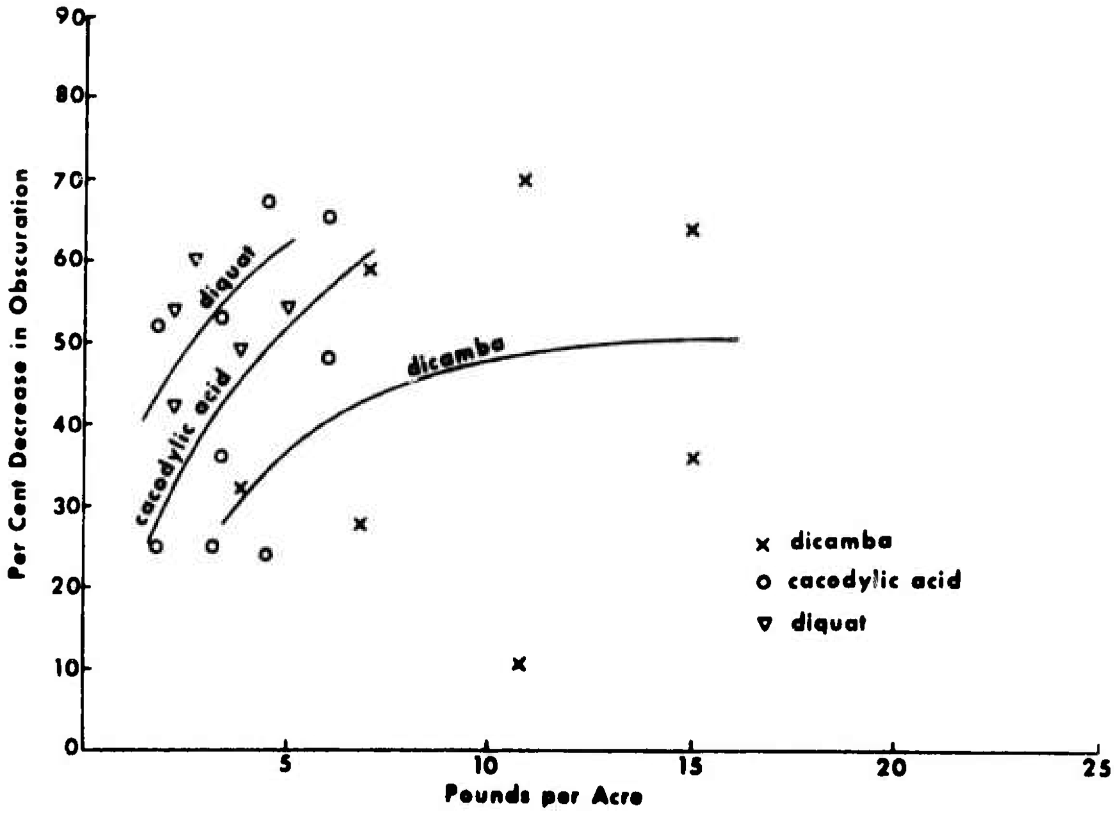
Chemical and Treatment	Rate, lb/acre	Mean %[a/] Target Visibility Initial	Maximum	Ratio Maximum/Initial Visibility	Months to Maximum Visibility
Purple					
	5.6	27	48	1.7-2.4	2-3
	6.0	14	43	2.5-3.4	4-5
	6.5	30	37	1.2-1.3	2-4
	7.0	26	35	1.2-1.2	2-3
	7.8	36	42	1.2-1.2	2
	9.5	29	52	1.7	2
	9.8	21	41	2.3-2.5	5-6
	10.0	25	40	1.3-1.9	3
	10.3	20	41	1.3-4.9	2-3
Usual	14.6	21	37	1.8-2.5	3-4
Rate	18.0	23	61	2.3-2.8	3-5
of	20.0	27	47	1.9	2
Treatment	22.0	29	45	1.3-2.2	1-2
	27.0	22	48	1.7-2.9	2-4
	30.0	40	65	1.6	3
Orange					
	5.5	18	36	1.8-2.1	3-4
	6.6	25	41	1.5-1.7	3
	8.2	25	46	1.8	2
	8.6	27	40	1.5	1
	8.8	13	36	2.6-2.7	1-2
	10.0	11	30	3.0-4.0	1-3
	11.4	19	49	2.3-3.0	1-2
Usual	12.8	27	49	1.8	3
Range	15.2	34	48	1.2-1.7	1-2
of	21.0	19	43	2.0-2.5	2-3
Treatment					
Cacodylic Acid					
	1.8	32	60	1.5-3.0	2
	3.4	21	60	2.5-3.4	2-4
	6.0	29	55	1.3-3.6	0.7-1

TABLE A-1 (Concluded)

Chemical and Treatment	Rate, lb/acre	Mean %[a] Target Visibility Initial	Mean %[a] Target Visibility Maximum	Ratio Maximum/Initial Visibility	Months to Maximum Visibility
Diquat					
	2.2	30	55	1.7-2.0	2
	2.8	22	41	1.5-2.8	0.5-0.7
	3.8	36	55	1.5-1.6	1.2
	5.0	18	42	2.2-2.7	0.5-3
Tordon + 2,4-D					
	2.3 + 5.3	10	58	5.1-7.9	6
Tordon + Diquat					
	2.3 + 2.5	28	54	1.7-2.5	5-6

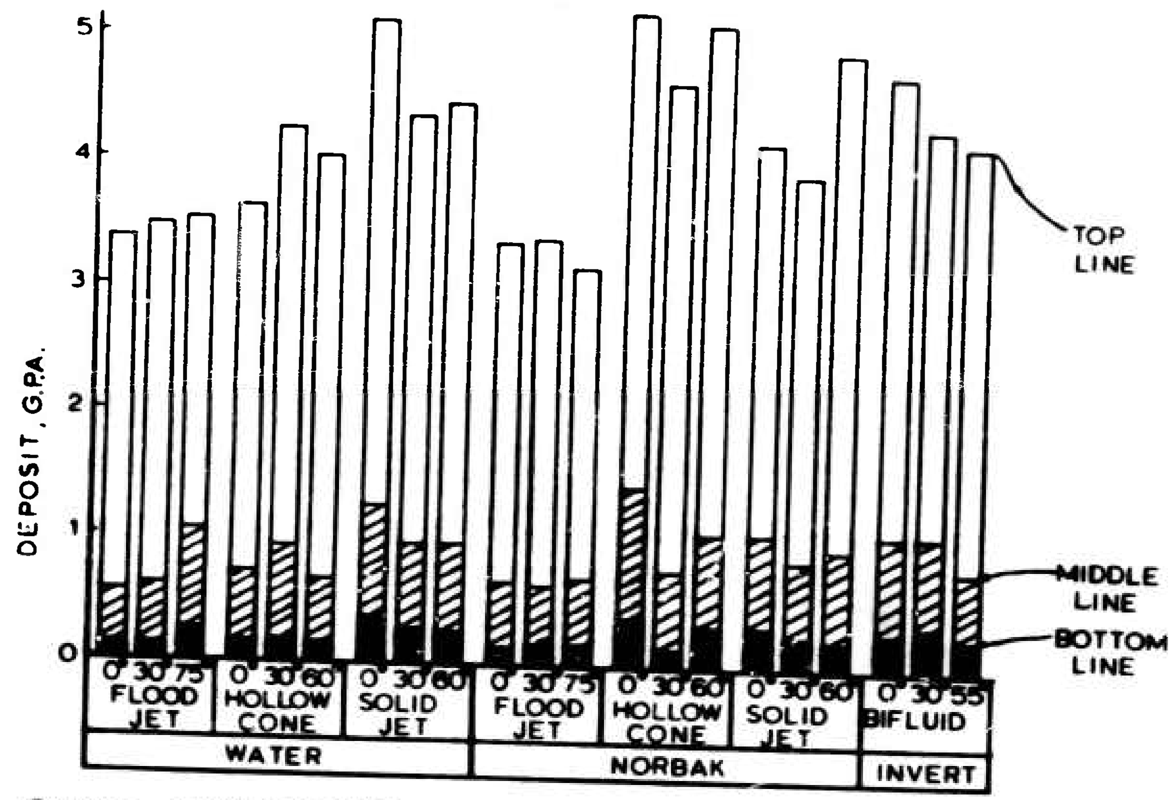
a/ Data based on percentage of target visible at distances of 10, 15, and 20 meters.

Source: Darrow, R. A., G. B. Truchelut and C. M. Bartlett, Oconus Defoliation test program. U. S. Army Biological Laboratories, Technical Report no. 79, July 1966, ARPA Order 423.



Source: Darrow, R. A., G. B. Truchelut and C. M. Bartlett, Oconus defoliation test program. U. S. Army Biological Laboratories, Technical Report No. 79, July 1966, ARPA Order 423

Figure A-1 - Defoliation Response of Dicamba, Cacodylic Acid, and Diquat in Relation to Rate of Application. Data represent plot values of maximum percent decrease in obscuration.



Source: Tschirley 1967.

Figure A-2 - Penetration of Aerial Spray through Two-Story Tropical Forest Strata. Top line shows deposit volume at the top canopy. Middle line is deposit volume below canopy, above the intermediate foliage. Bottom line is spray penetrating both levels of foliage as measured a few feet above the ground.

TABLE A-2

EFFECTS OF PURPLE, ORANGE, AND RELATED HERBICIDES ON UPPER CANOPY FOLIAGE AS MEASURED[a/] BY CHANGE IN VERTICAL OBSCURATION

Chemical		Rate, lb/acre a.e.[b/]	Maximum % Decreased Obscuration	Months: to Max. Effect	Months: Duration Max. Effect	Months: to 50% Recovery
			0.5 to 1.0 gal/acre (4 to 8.5 lb/acre)			
Purple		5.6	47.0	1.7	1.5	4.0
		6.0	78.0	3.0	1.5	6.0
		6.5	42.0	2.0	2.0	12.0
		7.8	45.0	2.0	1.0	4.0
		7.4	52.5	2.5	1.5	4.5
	Mean	6.7	52.9	2.2	1.5	6.1
Orange		6.0	38.5	2.0	1.0	3.0
		5.6	70.0	2.0	2.0	3.0
		6.6	61.5	2.2	2.0	-[c/]
		8.6	24.0	2.0	1.0	6.0
	Mean	6.7	48.5	2.1	1.5	4.0
			1.0 to 1.5 gal/acre (8.5 to 12.5 lb/acre)			
Purple		10.3	61.0	3.0	6.0	6.0
		10.0	47.5	1.5	1.7	3.5
		10.3	50.0	3.5	2.0	6.5
		9.8	81.5	2.7	1.5	6.5
	Mean	10.1	60.0	2.7	2.8	5.6
Orange		11.4	68.0	2.5	-	-
		8.8	64.0	2.5	-	-
		10.0	66.0	1.0	2.0	4.0
	Mean	10.1	66.0	2.0	2.0	4.0
			1.5 to 2.0 gal/acre (12.5 to 17.5 lb/acre)			
Purple		14.6	52.5	1.5	1.0	4.0
		15.4	75.0	1.0	3.0	5.0
	Mean	15.0	63.75	1.2	2.0	4.5
Orange		15.2	72.0	1.7	-	-

TABLE A-2 (Concluded)

Chemical		Rate, lb/acre a.e.[b]	Maximum % Decreased Obscuration	Months: to Max. Effect	Months: Duration Max. Effect	Months: to 50% Recovery
2.0 to 2.5 gal/acre (17.5 to 22.5 lb/acre)						
Purple		18.0	85.0	6.0	3.0	9.5
		22.4	63.0	3.0	1.5	> 4.0
	Mean	20.2	79.0	4.5	2.25	> 6.75
Orange		21.5	95.0	4.0	4.0	> 8.0
3.0 gal/acre (25 to 27 lb/acre)						
Purple		25.0	71.5	3.0	6.0	>12.0
		25.8	83.0	4.0	2.0	7.0
		27.0	70.0	4.5	3.0	10.5
	Mean	25.9	74.8	3.8	3.7	9.8
Cacodylic Acid		1.8	38.5	1.5	0.75	2.0
		3.2	12.5	2.0	0.5	1.5
		3.4	44.5	1.75	1.0	3.0
		4.5	45.5	0.75-1.0	0.5	2.0
		6.0	56.5	0.75-1.0	1.0	> 5.0
Diquat		2.2	48.0	1.0	1.0	2.25
		2.7	60.0	0.5	0.5	1.25
		2.8	38.2	1.75	1.25	-
		3.8	47.5	1.5	0.5	2.0
		5.0	54.0	2.0	1.5	-

a/ Data represent means of individual treatments and rate groups.
b/ Acid equivalent.
c/ No data. Readings incomplete at time of publication.

Source: Darrow, R. A., G. B. Truchelut and C. M. Bartlett, Oconus defoliation test program. U. S. Army Biological Laboratories, Technical Report No. 79, July 1966, ARPA Order 423.

TABLE A-3

PERCENTAGE DEFOLIATION RESULTING FROM TREATMENTS ON MIXED HARDWOODS NEAR LIVINGSTON, TEXAS

Treatments Applied in May 1966

	Treatment		Time After Treatment				
Herbicide	Gal/Acre	Lb/Acre	1 Wk. (%)	2 Wk. (%)	4 Wk. (%)	13 Wk. (%)	3 Mo. (%)
Orange	1.5	12	10	30	50	90	50
	3.0	24	20	40	60	95	50
	6.0	48	20	40	70	95	95
2,4,5-T Plus Picloram (4:1)	1.5	7.5	10	20	40	95	70
	3.0	15	10	30	50	95	90
	6.0	30	20	35	60	95	99
Picloram	1.5	3	10	20	30	90	50
	3.0	6	10	20	40	95	85
	6.0	12	10	35	60	95	90
Paraquat	1.5	3	50	50	50	20	10
	3.0	6	30	30	40	40	10
	6.0	12	30	30	40	20	5

Source: Tschirley, F. H., Response of tropical and subtropical woody plants to chemical treatments. ARS, U. S. Dept. of Agriculture Technical Report (no number) 1967, ARPA Order 424. (CR-13-67)

TABLE A-4

RECOMMENDED APPLICATION LEVELS FOR NONCROPLAND[a]

Woody Plants

Herbicide	Lb. active Ingredient per acre	Herbicide	Lb. active Ingredient per acre
AMS	7-10 in 2 gal water	Silvex	2-4
AMS	60 in 100 gal water	2,3,6-TBA	10-20
Fenuron	12-25	2,4,5-T	2-4
Fenuron TCA	12-25	2,4-D	2-4
Picloram	6-8.5	2,4-D, 2,4,5-T of 2:1 or 1:1 mixture	2-4

Mixed Herbaceous Broad-Leaved and Grass Weeds

Amitrole	3-5	Diuron or Monuron	20-40, 40-60
Amitrole T	6-12	Erbon	120-160
AMS	50,100; 100-1000	Monuron-TCA	20-40, 40-60
Borate Sodium	1300-5200	Paraquat (cation)	0.5-2
Bromacil	3-6, 10-25	Prometone	10-15, 20-60
Chlorate Sodium	300-600, 700-1300	Simazine Atrazine	5-20, 20-40
Dicamba	1-4, 4-8		

Broad-Leaved Herbaceous Weeds (selective control in desirable grasses)

PBA	20-60	2,3,6-TBA	10-30
Picloram	2-3	2,4-D	2-4
TCBP	8-16	2,4,5-T	2-4

Weedy Grasses Where Control of Broad-Leaved Weeds Not Necessary

Aromatic oil (annual)	40-80	Dalapon	20-30
Dalapon (annual)	5-10	DSMA or MSMA	2.5-5 lb/100 gal
DNBP or PCP (annual) fortified fuel oil	40-80 gal	Sodium TCA	100-150
Aromatic oil	120-160 gal	Amitrole	8-12
Dalapon	10-15	Amitrole-T	4-6

a/ U. S. Department of Agriculture, Agriculture Handbook No. 332, p.54 (1967).

TABLE A-5

SOIL MICROORGANISMS WHICH DECOMPOSE CHLORINATED ALIPHATIC ACIDS

Organism	Monochloroacetic acid	Dichloroacetic acid	Trichloroacetic acid	2-Chloropropionic acid	3-Chloropropionic acid	2,2-Dichloropropionic acid	2,2,3-Trichloropropionic acid
	Compound						
Bacteria							
Agrobacterium sp.		48,49,54		54	54	48,49,67,14,54	
Pseudomonas sp.	47,42,54[a]	42,54	54	42,54	42,54	42,67,64,14,8	54
Arthrobacter sp.	54	54	48,49,54	54	54	55,47,54	54
Micrococcus sp.						67	
Alcaligenes sp.	54			54	54	55,54	
Bacillus sp.		54		54	54	55,54	
Pseudomonas dehalogens			44,43			44,43	
Flavobacterium sp.						87	
Fungi							
Trichoderma viride	48,49,50	48,49,13	48,49	50		55	
Clonostachys sp.	48,50	50		50			
Penicillium sp.						42,55	
Aspergillus sp.						42	
Acrostalagmos sp.	50	50		50			
Penicillium lilacinum						55	
Penicillium rouqueforti	48						
Actinomycetes							
Nocardia sp.	42,54	42		42,54	42,54	42,55,54	
Streptomyces sp.						42,55	

a/ The numbers in the table refer to the references in the Bibliography on the following page.

Source: Modified from Kearney, P. C., C. I. Harris, D. D. Kaufman, and T. J. Sheets, Behavior and fate of chlorinated aliphtic acids in soils, pp. 14-15 from Advances in Pest Control Research, VI, R. L. Metcalf (Ed.), Interscience Publishers, N. Y. (1965).

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TABLE A-6

SOIL ORGANISMS WHICH DECOMPOSE HERBICIDES

Organism	2,4-dichlorophenoxyacetic acid (2,4-D)	2-methyl-4-chlorophenoxyacetic acid (MCPA)	2,4,5-trichlorophenoxyacetic acid (2,4,5-T)	γ (2,4-dichlorophenoxy) butyric acid (2,4-DB)	γ (2-methyl-4-chlorophenoxy) butyric acid (MCPB)	α,α-dichloropropionic acid (dalapon)	Trichloroacetic acid (TCA)	2,4-dinitro-o-cresol (DNC)	3-(p-chlorophenyl)-N',N' dimethyl urea (monuron)
Eubacteriales									
Pseudomonadaceae									
Pseudomonas fluorescens									
P. putida									
Pseudomonas sp.									15
Mycoplana sp.	41[a]	41	41						
Rhizobiaceae									
Agrobacterium sp.						17,19			
Corynebacteriaceae									
Corynebacterium simplex								12	
Corynebacterium sp.	32								
Bacterium globiforme	2								
Bacterium "2"	20	20							
"Bacterium 3 Cl" (Arthrobacter sp.)							17,19		
Achromobacteriaceae									
Achromobacter sp.	4,37,38,39	37,38,39	4						
Flavobacterium aquatile	20								
F. peregrinum	37,38,39								
Actionomycetales									
Nocardia coeliaca	20								
N. opaca				42	42				
N. corallina									
Nocardia sp.	40								
Fungi									
Trichoderma viride							17,19		
Clonostachys sp.									

a/ Modified from Audus, L. J., Microbial breakdown of herbicides in soils, p. 6, from Herbicides and the Soil, Eds. E. K. Woodford and G. R. Sager, Blackwell Scientific Publications, Oxford (1960).

Source: The numbers in the table refer to the references in the Bibliography on the following page.

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TABLE A-7

MICROBIAL AND PHOTODECOMPOSITION OF HERBICIDES

Herbicides	Microbial Breakdown	Photodecomposition
Amitrole	Approximately 2-3 weeks in moist, warm soil.	Minor.
Atrazine	Microbial action probably accounts for the major breakdown of atrazine in the soil. A range of soil microorganisms can utilize it as a source of energy and nitrogen. The effect of atrazine on these and other organisms appears to be small.	The significance of photodecomposition and/or volatilization of atrazine from soil is not fully understood. Available data indicate that both occur to some extent if high temperatures and prolonged sunlight follow application before precipitation, but that these factors are of little direct importance in atrazine dissipation under most field conditions. Atrazine is more subject to UV and volatility losses than simazine, but probably about equal or less subject to these losses compared to the commercial methylmercapto or methoxytriazines.
Bromacil	Microbiological degradation apparently is the major mode of disappearance from soils. Soil diphtheroids and Pseudomonas species are among the organisms involved.	Tests at elevated temperatures and long exposures to sunlight indicate that loss from soil due to volatilization and photodecomposition are negligible.
Cacodylic acid		None.
Dalapon	Breaks down rapidly and completely in soil. Several organisms have been isolated and identified.	
Diquat	Although unavailable to plants and higher organisms, diquat in the soil may be subject to attack by microorganisms, which are known to be capable of extracting even tightly bound elements from soils. Experiments with microorganisms in culture media have shown that certain of these are capable of decomposing diquat in the absence of soil (though none has as yet been unequivocally proved to do so on adsorbed diquat).	Loss of diquat can occur via photochemical decomposition.
Diruon	Microbes are the primary factor in the disappearance of diruon from soils (see monuron).	Losses by photodecomposition or volatility probably are insignificant except when diruon is exposed on the soil surface for several days or weeks under hot, dry conditions.
DSMA		None.
Endothal	Disappears from soil and water by microbiological breakdown at rates dependent upon soil temperature, moisture, type and microbiological activity.	

TABLE A-7 (Concluded)

Herbicides	Microbial Breakdown	Photodecomposition
Monuron	Microbes are the primary factor in the disappearance of monuron from soils. Some organisms that can use monuron as sole source of carbon include bacteria such as Pseudomonas, Xanthomonas, Sarcina, and Bacillus, and fungi such as Penicillium and Aspergillus.	Losses by photodecomposition or volatility probably are insignificant except when monuron is exposed on the soil surface for several days or weeks under hot, dry conditions.
Paraquat	See diquat	Loss of paraquat can occur via photochemical decomposition by irradiating thin layers of soil. Radio-labelled paraquat has been used in such studies, which have shown that the degradation of paraquat to simple and harmless substances can occur under field conditions.
Simazine	Microbial action probably accounts for the major breakdown of simazine in soil. A range of soil microorganisms can utilize it as sources of energy and nitrogen. The effects of simazine on these and other soil organisms appears to be small.	Photodecomposition and/or volatilization of simazine from soil is little understood. Available data would suggest that these factors are of little importance in simazine dissipation.
Sodium arsenite		
2,4,5-T	Broken down more slowly than 2,4-D, due to the addition of another Cl atom.	
2,3,6-TBA	Microbial breakdown is slow although degradation in biologically active soil has been demonstrated with the use of Cl^{36}-tagged trichlorobenzoic acid. Up to 50 percent of the Cl^{36} was recovered as ionic chloride within 5 months. (Dewey, O.R., R. V. Lindsay, and G. S. Hartley. 1962. Biological destruction of 2,3,6-trichlorobenzoic acid in soil. Nature 195: 1232.)	Relatively stable to loss from these factors.
TCA	Breakdown by microorganisms is slower than that of dalapon.	

Source: Abstracted from Herbicide Handbook of The Weed Society of America published by W. F. Humphrey Press Inc., Geneva, N. Y. (1967).

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CHAPTER VII. HERBICIDE RESIDUES AND THEIR PERSISTENCE

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CHAPTER IX. ECOLOGICAL CONSEQUENCES OF HERBICIDE USE

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GLOSSARY

(Identification of non-chemical herbicide names used in this report)

Amiben*	3-amino-2,5-dichlorobenzoic acid	(Amchem)
Amitrole	3-amino-1,2,4-triazole	
Amitrole-T	amitrole + ammonium thiocyanate	
Ametryne	2-ethylamino-4-isopropylamino-6-methylmercapto-s-triazine	
Ammate	ammonium sulfamate	
ATA	aminotriazole	
Atrazine	2-chloro-4-ethylamino-6-isopropylamino-s-triazine	
BMM	disodium tetraborate (93.1%), monuron (3%) and TBA (1%)	
Bromacil	5-bromo-3-sec-butyl-6-methyluracil	
Cacodylic acid	Dimethylarsinic acid	
CDEC	2-chloroallyl diethyldithiocarbamate	
CPA	chlorophenoxyacetic acid	
2,4-D	2,4-dichlorophenoxyacetic acid	
" acetamide	2,4-dichlorophenoxyacetamide	
" BE	butyl ester of 2,4-D	
" BEE	butoxyethyl ester of 2,4-D	
" DMA	dimethylamine salt of 2,4-D	
" IOE	isooctyl ester of 2,4-D	
" IPE	isopropyl ester of 2,4-D	
" K salt	potassium salt of 2,4-D	
" PGBEE	propylene glycol butyl ether ester of 2,4-D	

* Registered Trademarks

Dalapon	2,2-dichloropropionic acid
Dicamba	2-methoxy-3,6-dichlorobenzoic acid
DCMA	N-(3,4-dichlorophenyl)methacrylamide
Dichlobenil	2,6-dichlorobenzonitrile
Dichlone	2,3-dichloro-1,4-naphthoquinone
Diphenamid	N,N-dimethyl-2,2-diphenylacetamide
Diquat	6,7-dihydrodipyrido(1,2-a:2',1'-c) pyrazidinium salt
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea
DSMA	disodium methanearsonic acid
Dybar*	3-phenyl-1,1-dimethylurea (duPont)
Endothall	7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid
EPTC	ethyl N,N-dipropylthiocarbamate
Erbon	2-(2,4,5-trichlorophenoxy)-ethyl-2,2-dichloropropionate
Fenac	2,3,6-trichlorophenylacetic acid
Fenuron	3-phenyl-1,1-dimethylurea
Herban*	3-(hexahydro-4,7-methanoindan-5-yl)-1,1-dimethylurea (Hercules)
Hibor	sodium metaborate 1 lb, sodium chlorate 0.7 lb and bromacil 0.3 lb/gal.
Isocil	5-bromo-3-isopropyl-6-methyluracil
Kuron*	2-(2,4,5-trichlorophenoxy)propionic acid PGBEE (see 2,4-D) (Dow)
MCPA	2-methyl-4-chlorophenoxyacetic acid
Monuron	3-(p-chlorophenyl)-1,1-dimethylurea

* Registered Trademarks

MSMA	monosodium methanearsonic acid	
Neburon	1-butyl-3-(3,4-dichlorophenyl)-1-methylurea	
Paraquat	1,1'-dimethyl-4,4'-bipyridinium salt	
PBA	polychlorobenzoic acid	
PCP	pentachlorophenol	
Picloram	4-amino-3,5,6-trichloropicolinic acid	
Planovin*	4-(methylsulfonyl)-2,6-dinitro-N,N-dipropylaniline	(Shell)
Randox*	N,N-diallylchloroacetamide	(Monsanto)
Siduron	1-(2-methylcyclohexyl)-3-phenylurea	
Silvex	2-(2,4,5-trichlorophenoxy)-propionic acid	
Simazine	2-chloro-4,6-bis(ethylamino)-s-triazine	
2,3,6- TBA	2,3,6-trichlorobenzoic acid	
TCA	trichloroacetic acid	
2,4,5-T	2,4,5-trichlorophenoxyacetic acid	
Telvar*	3-(p-chlorophenyl)-1,1-dimethylurea	(duPont)
Tordon*	4-amino-3,5,6-trichloropicolinic acid	(Dow)
" 10K	10% potassium salt of Tordon	
TPA	2,2,3- trichloropropionic acid	
2,4,5-TP	2-(2,4,5-trichlorophenoxy)-propionic acid	
Tritac*	2,3,6-benzyl propyleneglycol ether	(Hooker)
Trysben*	2,3,6-trichlorobenzoic acid	(duPont)
Urab*	3-phenyl-1,1-dimethylurea salt of trichloroacetic acid (Allied)	

* Registered Trademarks

Note: Abbreviations for some popular herbicide acid derivatives are listed above under 2,4-D

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13. ABSTRACT

An information survey including published literature and personal interviews with individuals knowledgeable in the fields of herbicide usage, animal ecology and plant ecology has been conducted for the purpose of assessing the ecological consequences of extensive or repeated use of herbicides for vegetation control. The general subjects discussed in this review include (1) herbicide production, usage and trends; (2) herbicide application to crop and noncroplands, especially forests, ranges, rights-of-way, waterways, ponds, lakes and reservoirs; (3) military usage of herbicides in Vietnam; (4) acute, subacute and chronic toxicities of 21 herbicides used primarily for noncropland application; (5) persistence and elimination of herbicides from the soil; (6) known ecological effects of vegetation removal by chemical methods (e.g., herbicides) and physical methods (e.g., bulldozing, fire, flooding, etc.), including both the effects on the biotic and the abiotic components. Specifically, consideration is given to the effects of herbicides on wildlife, wildlife habitat, endangered species, food chains, biotic potential, plant succession, animal succession, revegetation, climate, soil erosion, laterization and related topics; (7) some conclusion regarding the ecological changes are presented; and (8) some recommendations for further ecological investigations are given.

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Habitat						
Herbicides (21)						
Laterization						
Microorganisms						
Picloram						
Plant succession						
Pollution						
Residues						
Revegetation						
Rights-of-way						
Silvicides						
Soil erosion						
Toxicology						
2,4-D						
2,4,5-T						
Weed control						
Wildlife						